Large Area Picosecond Microchannel Plate Photodetectors

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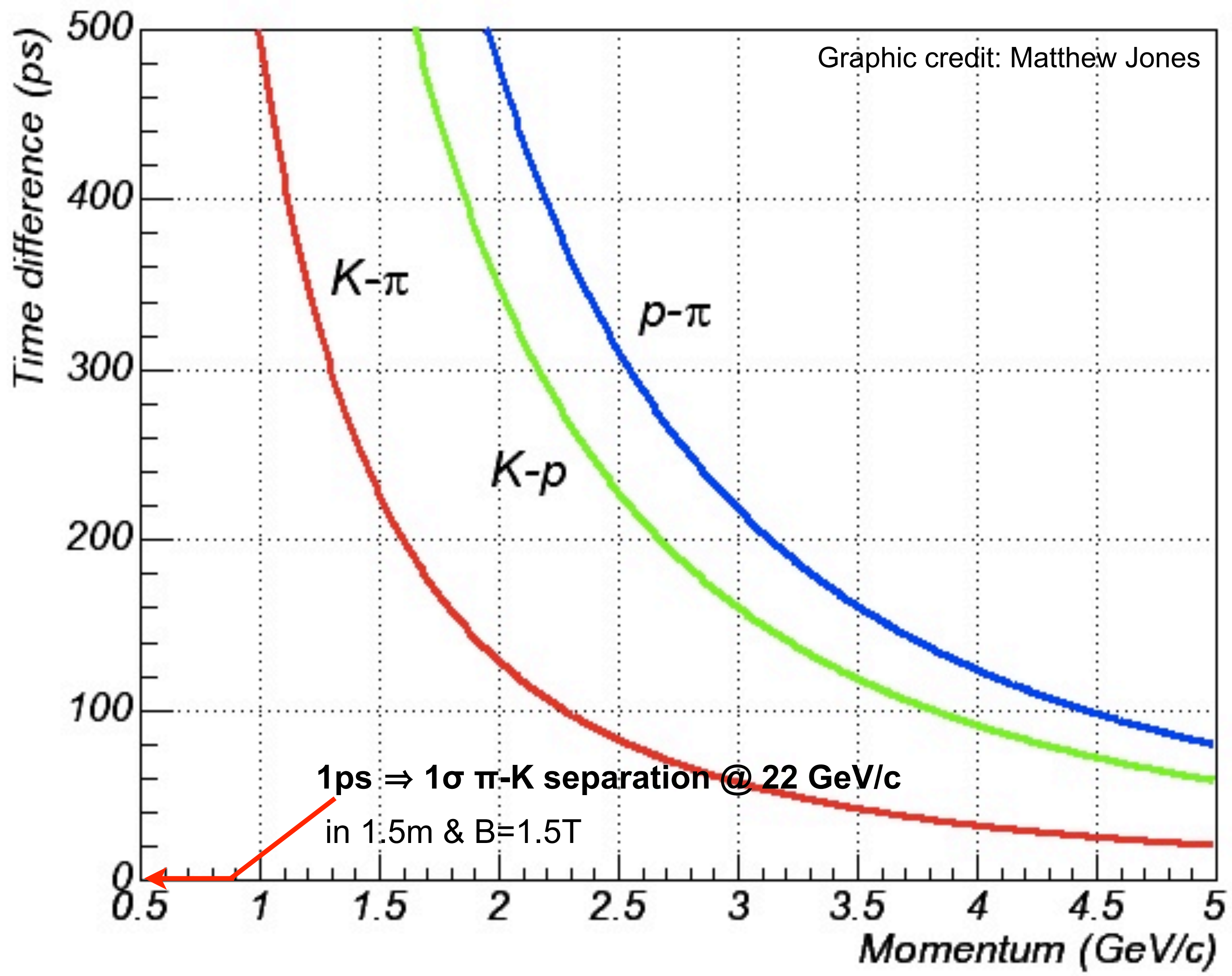
Tuesday 04 Sept 2012
for the LAPPD Collaboration

Motivation — Pushing the Limits of Time Resolution

- Project evolved from LDRD to improve Particle ID in colliding beam experiments

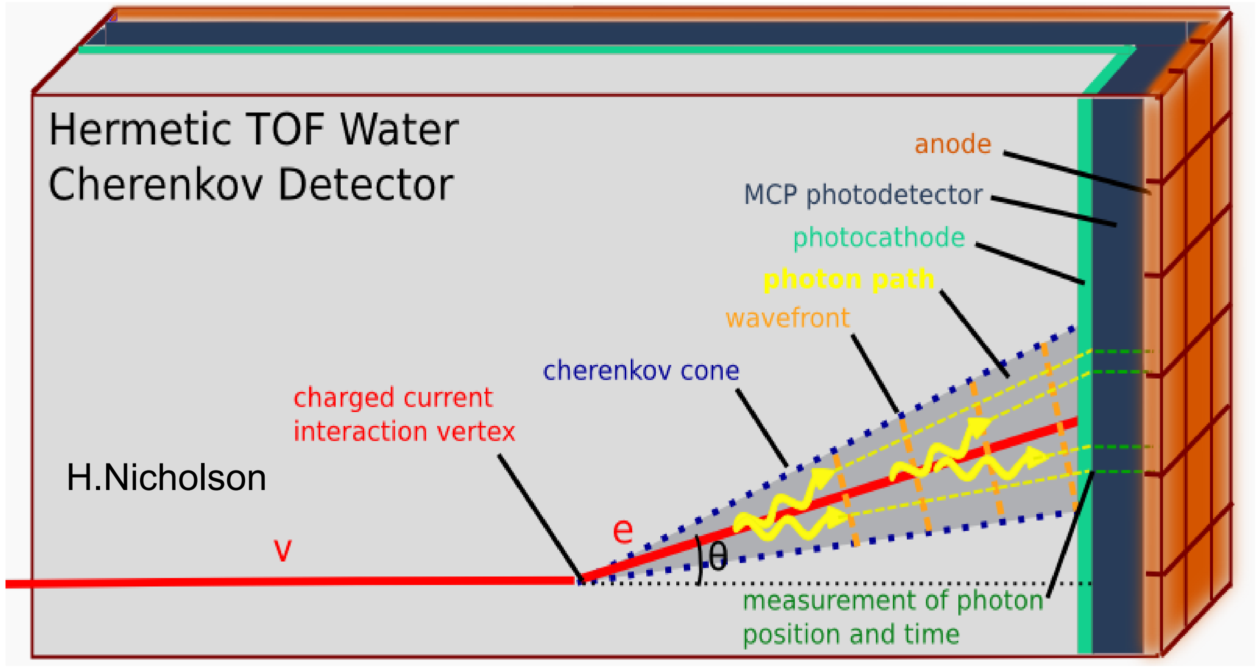


Goal: Measure ALL information ID quarks producing the jets. Need particle ID for momentum of 10's of GeV/c

Complete particle measurement: E, p + m(PID)
1ps time & 1mm space resolution

Applications — Tracking Neutrino Water Cherenkov Detector

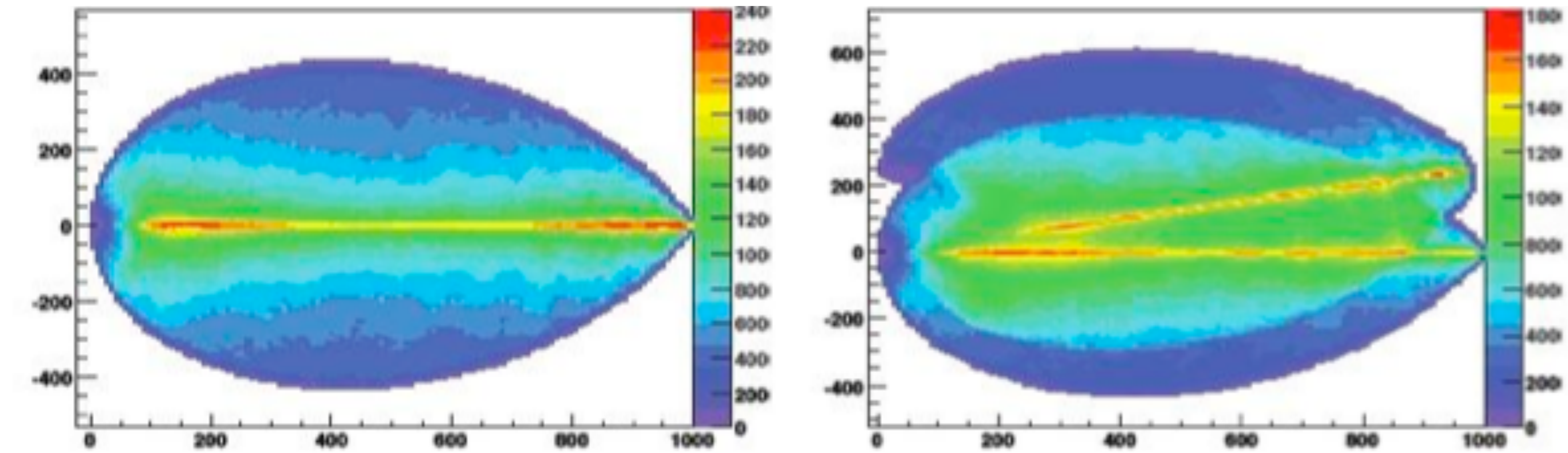
Technique: measure arrival time and position of photons and reconstruct tracks in water



Tesselation of detector with Large Area MCP-PMTs

Results of a toy Monte Carlo with perfect resolution

Color scale shows the likelihood that light on the Cherenkov ring came from a particular point in space. Concentration of red and yellow pixels cluster around likely tracks



Single track

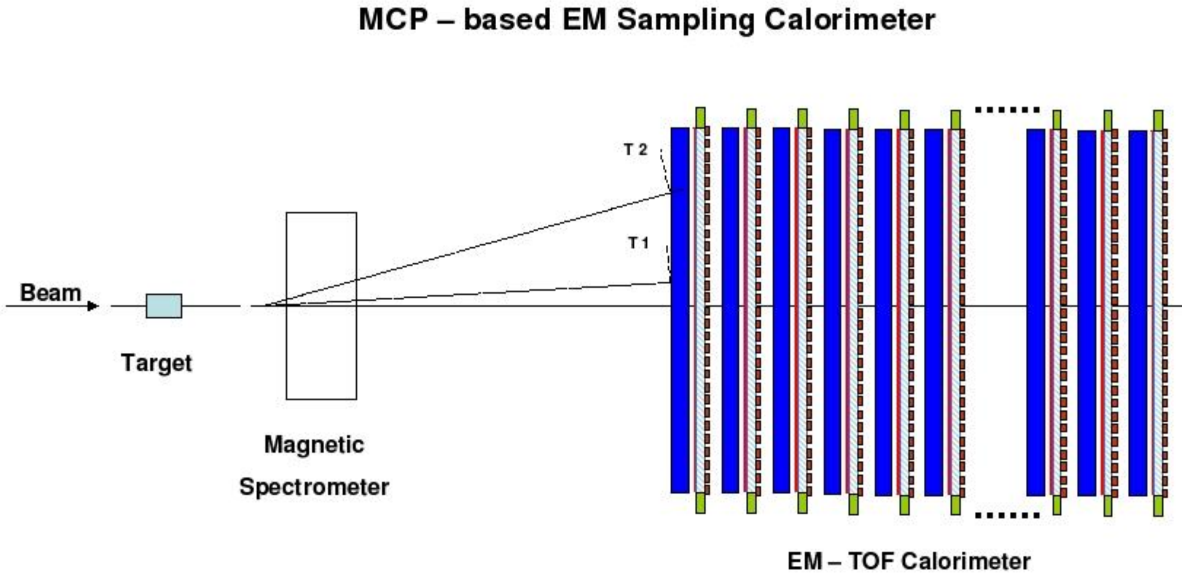
Two tracks displaced from a common vertex

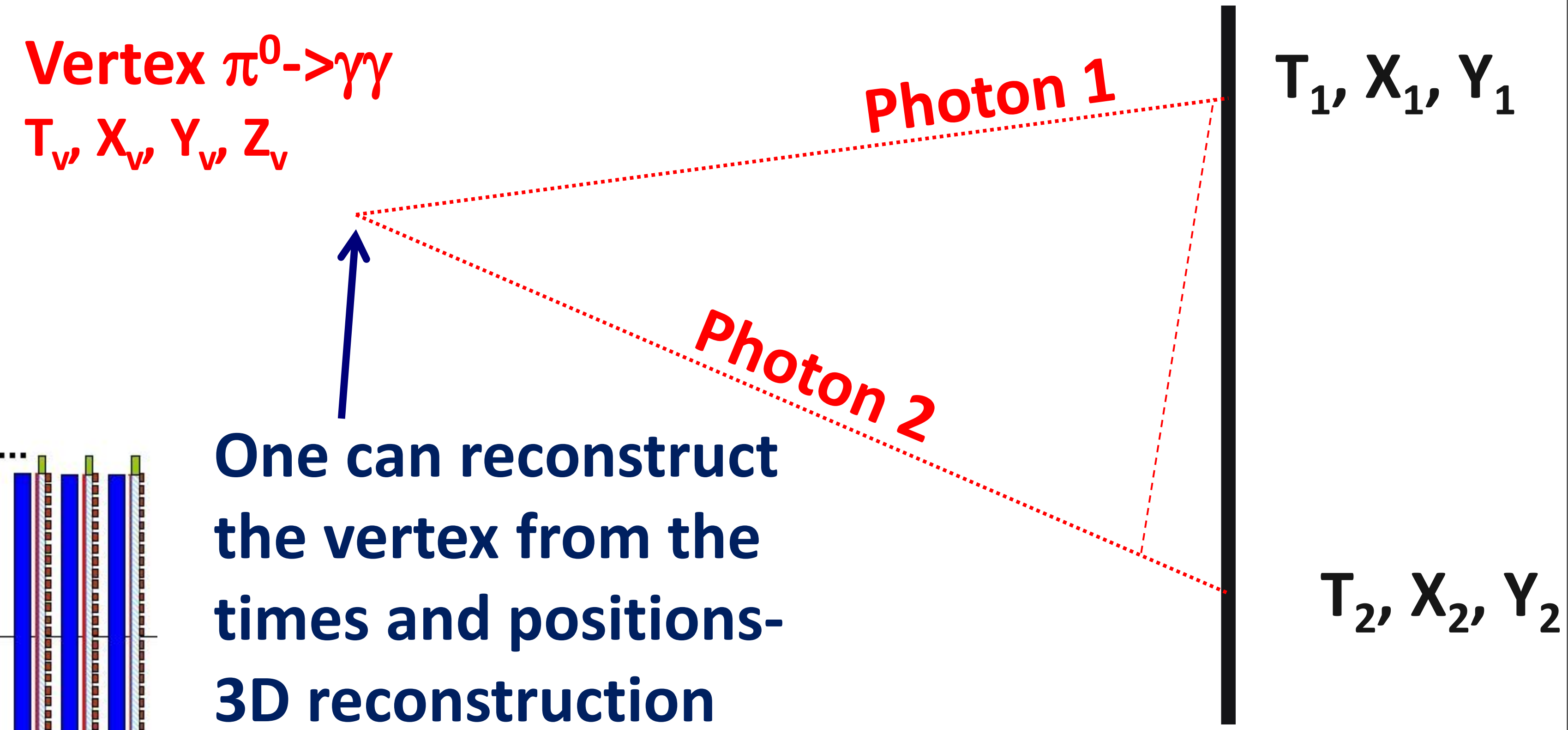
graphic credit: Matt Wetstein

Applications — Photon Vertexing

Rare Kaon Decays - $K_L \rightarrow \pi^o \nu \bar{\nu}$

Combination with precision energy resolution in calorimeter critical

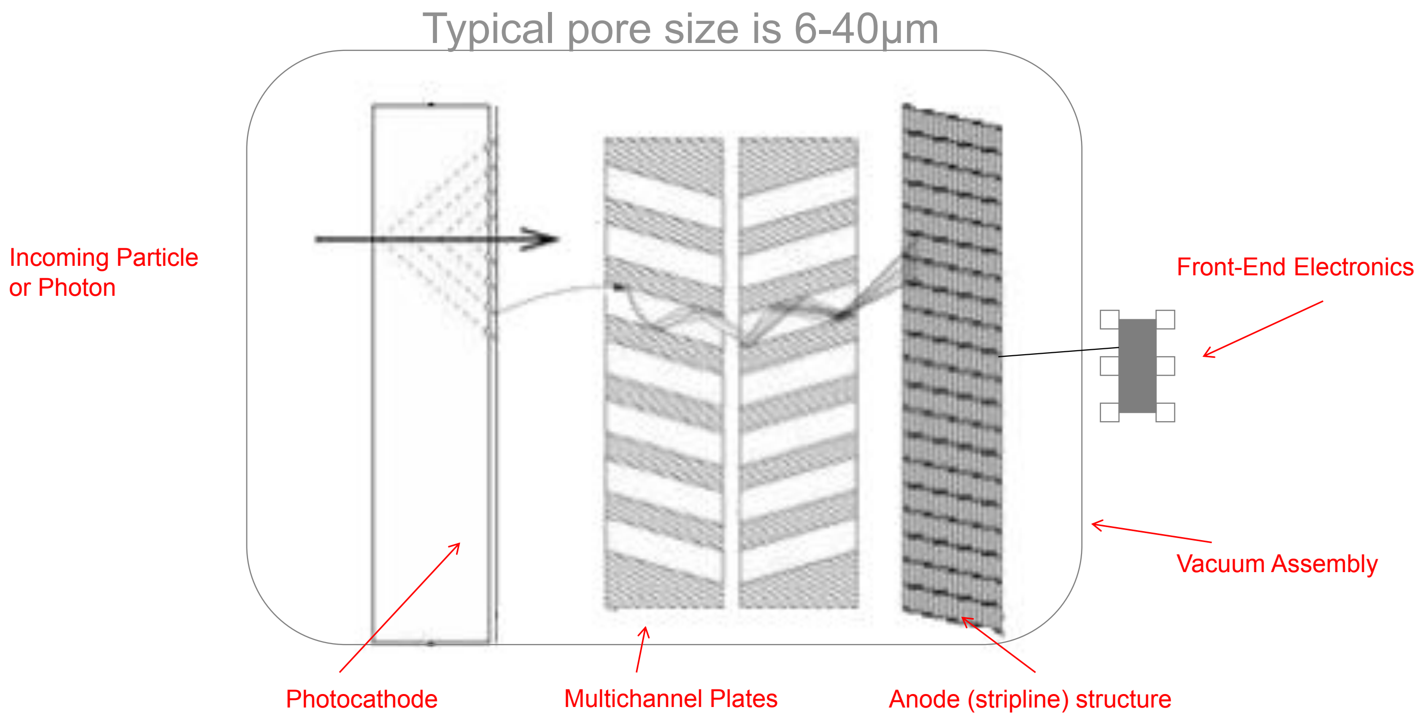




One can reconstruct the vertex from the times and positions- 3D reconstruction

Reduce combinatoric background for π^o

Microchannel Plate Photomultipliers



Existing commercial MCP-PMTs:

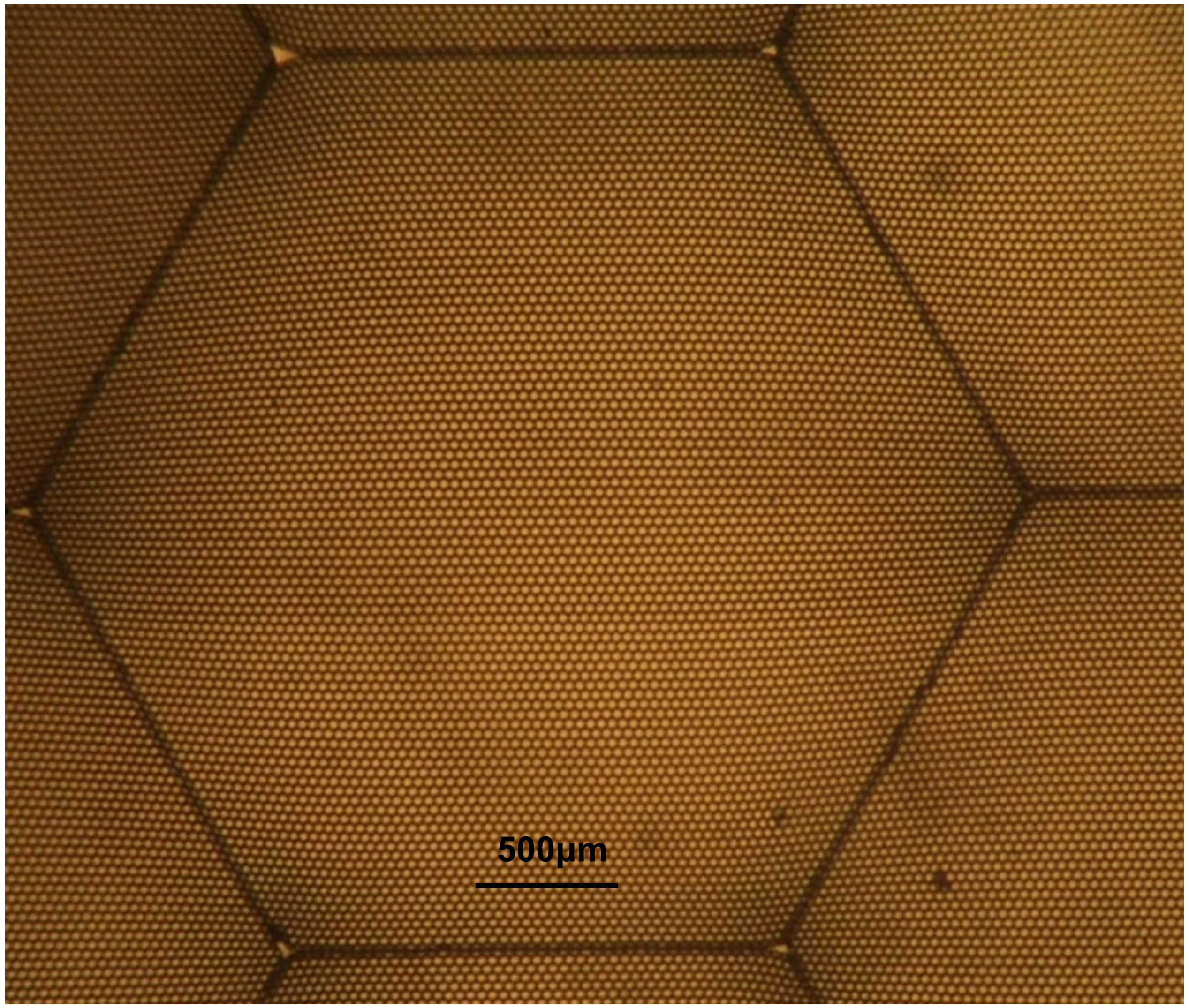
- Fabrication constrained by common material for substrate, resistive and emission layers
- ≤ ~25mm^2 active area
- Expensive

Components of the Large Area Picosecond Photodetector Development:

- Transformational improvement of MCP fabrication and size
  - 8”×8” borosilicate glass w/20&40µm pore
  - Resistive & secondary emissive functions separated into 2 materials via ALD coating
- Development of planar, large-area photocathodes
- Waveform sampling 10GSa/s electronics readout
- Development of economical hermetic packaging
  - Standard ceramic package w/InBi hot seal & HV/signal pins feedthru — SSL/UC-Berkeley
  - Inexpensive borosilicate all-glass w/thermopressure seal, pinless — Argonne/UChicago

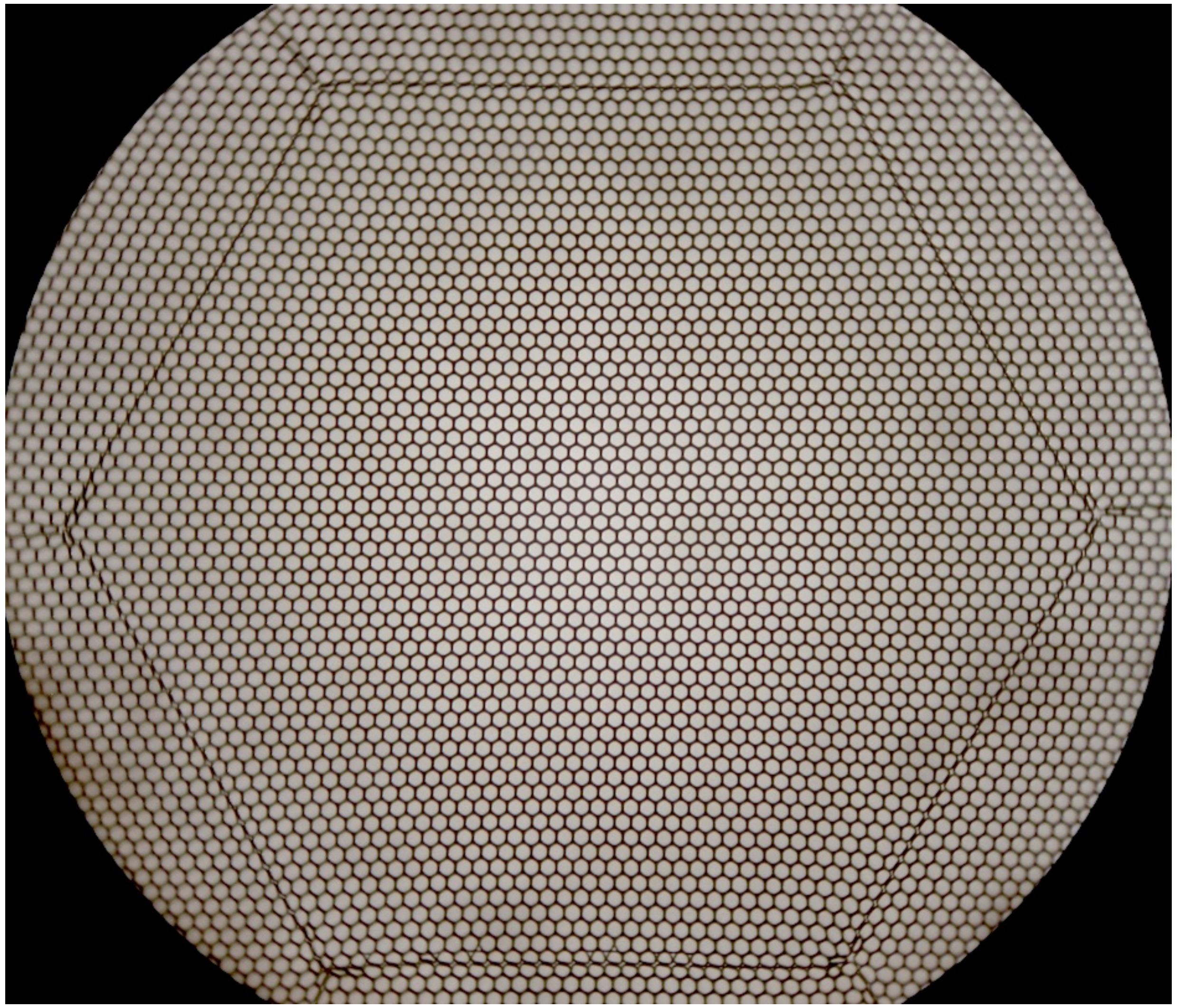
Development of Economical Borosilicate Capillary Arrays for MCPs — Industrial Partnership w/Incom, Inc

First block 2010



- Multifiber stacking
- Triple point gaps
- Pore crushing at multifiber boundaries

Most recent block 2012

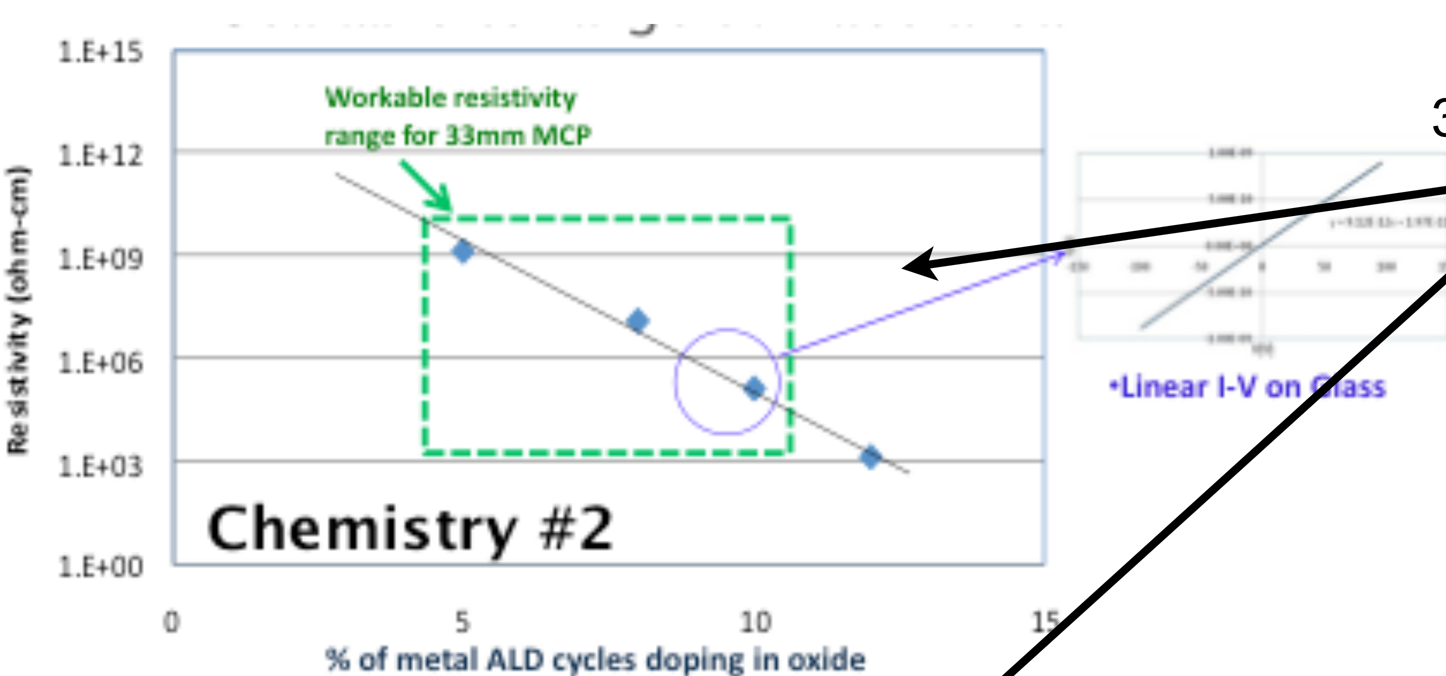


- Triple points mostly eliminated
- Minimal boundary pore distortion

Capillary array quality dramatically improved during last 2.5 years

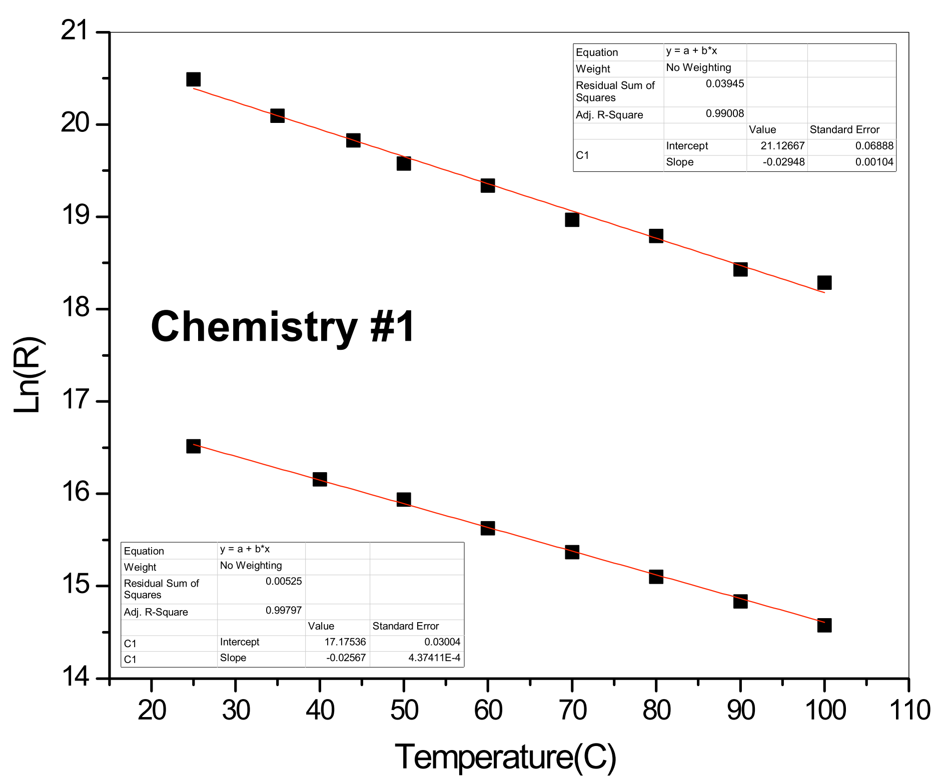
Future: Continued fusion and finish quality improvement, reduce pore size, larger L/D, reduce production cost

ALD Materials Development

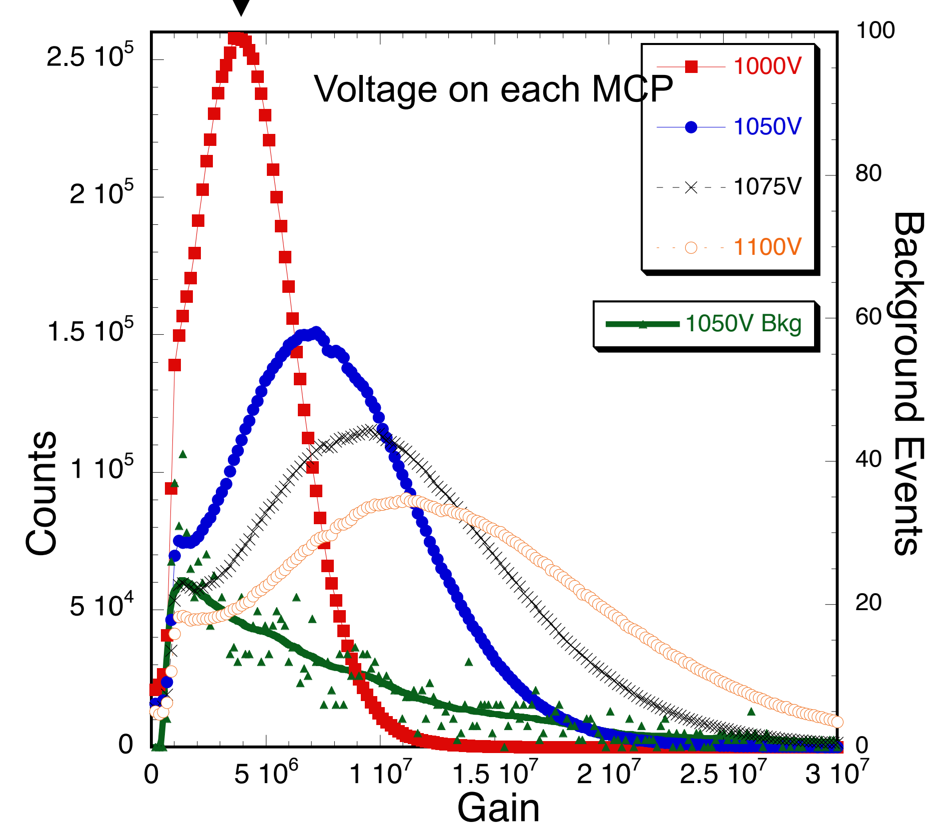


3 Resistive Chemistries invented by ANL ALD Group:

- **Tunable R over 6+ orders of mag.**
- **R vs. Temp. stable against thermal runaway**
- **Functionalized MCPs exhibit high gain**



G=4×10^6 @ 1000V



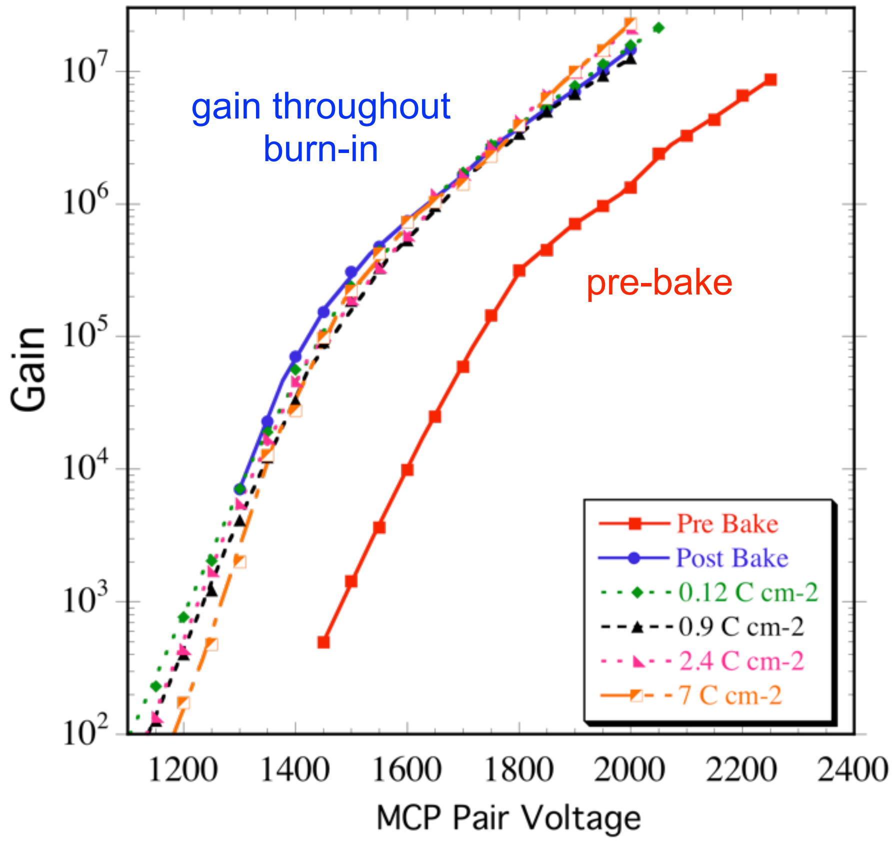
Pulse height amplitude distributions. MCP pair, 20μm pores, 8° bias, 60:1 L/d, 0.7mm pair gap with 300V bias. 3000 sec background.

ALD development: Anil Mane & Jeff Elam, Argonne ESD

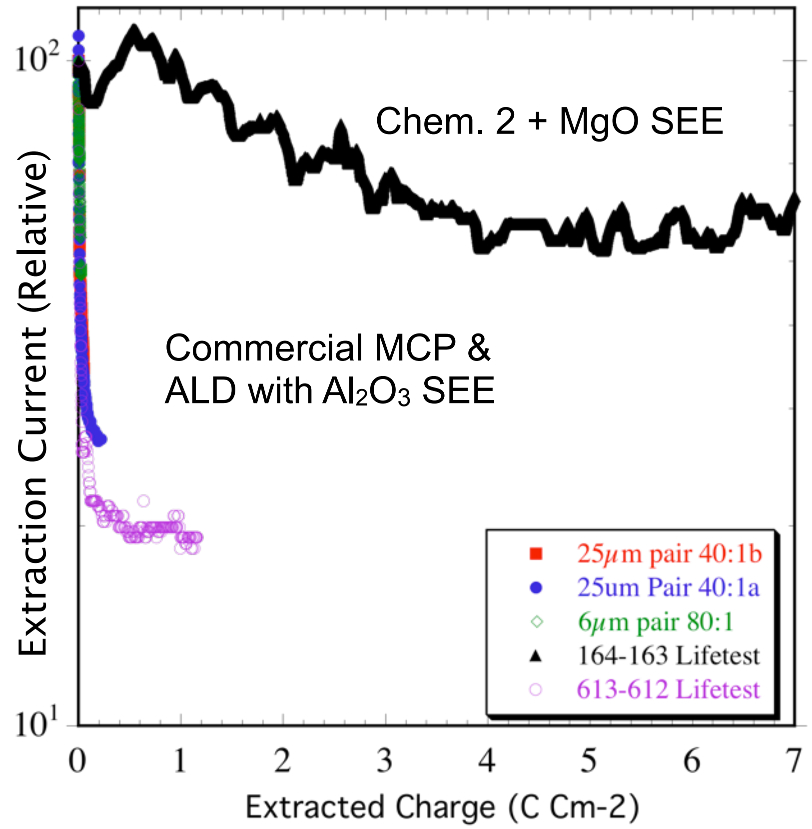
graphic: Ossy Siegmund, SSL

MCP Development & Testing

MCP LIfetest:
350˚C bakeout then 1-3μA "burn-in" to 7C/cm²

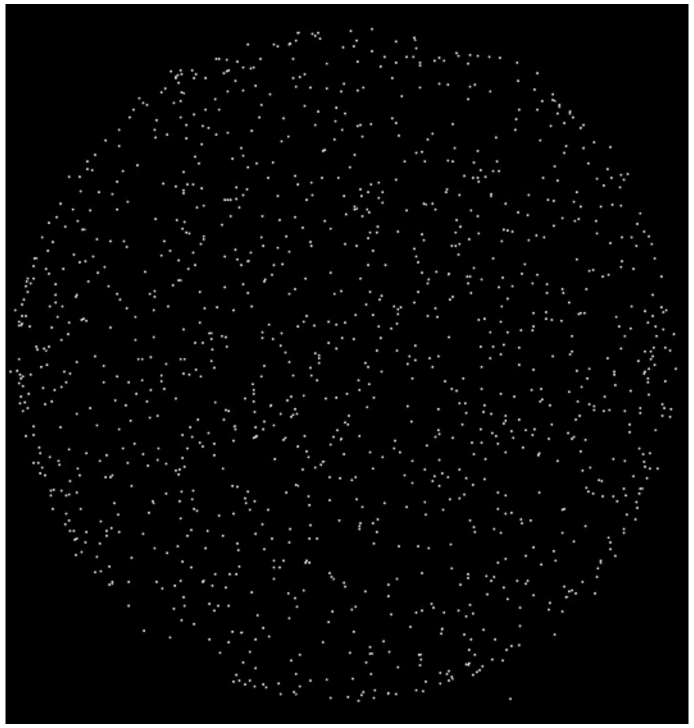


Gain curves of 33mm ALD MCP pair during conditioning.



UV illumination of ALD MCP pair compared with conventional MCPs.

Background Noise Measurement (separate from lifetest)



0.0845 events/cm²-s
7 x 10^6 gain

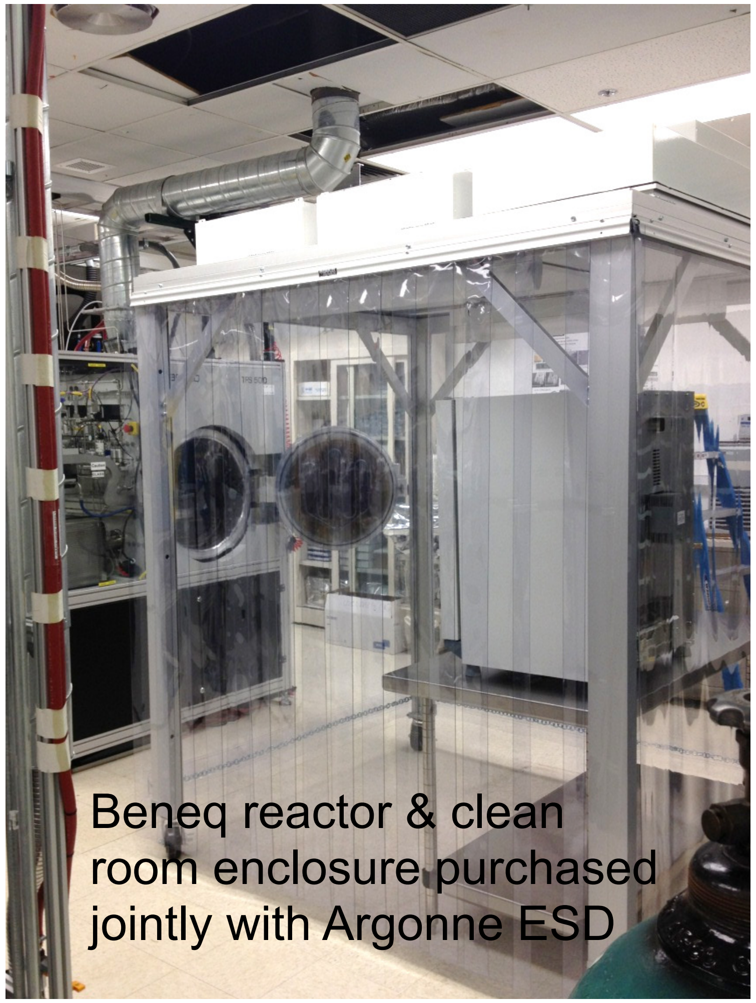
Rate comparable to cosmic bkgd

Desirable MCP properties with MgO SEE:

- **No precipitous initial gain decrease as seen in commercial MCPs.**
- **Little or no aging up to 7C/cm².**
- **MgO SEE produces low-noise MCP**

graphics: Ossy Siegmund & Jason McPhate, SSL

MCP Development — Scaling to Large Area

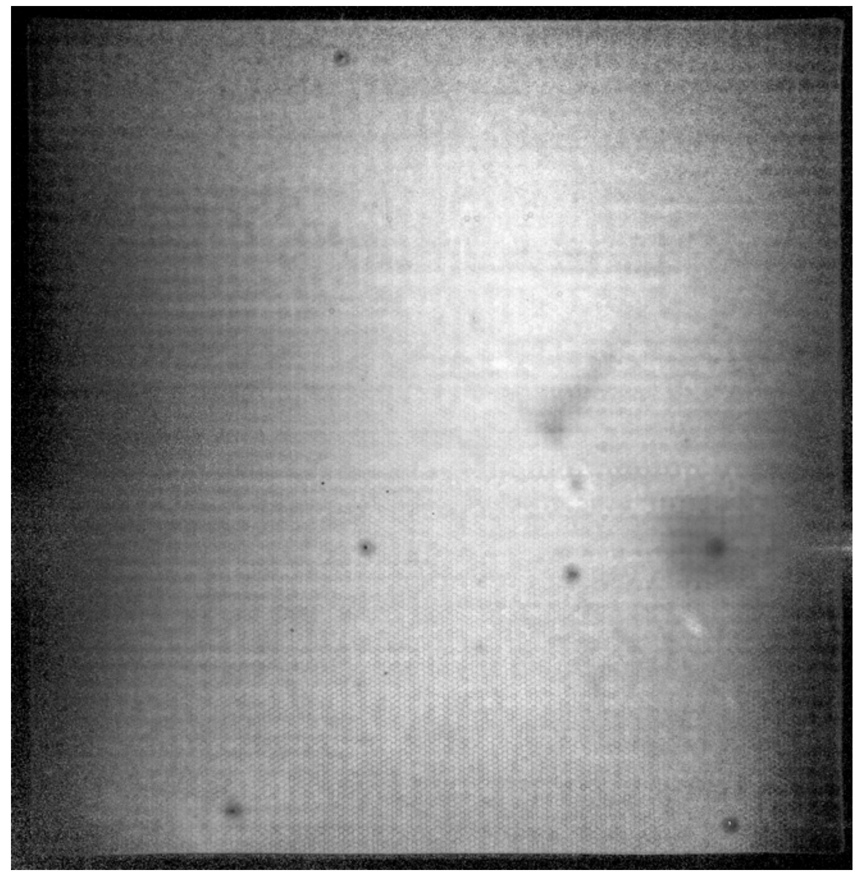


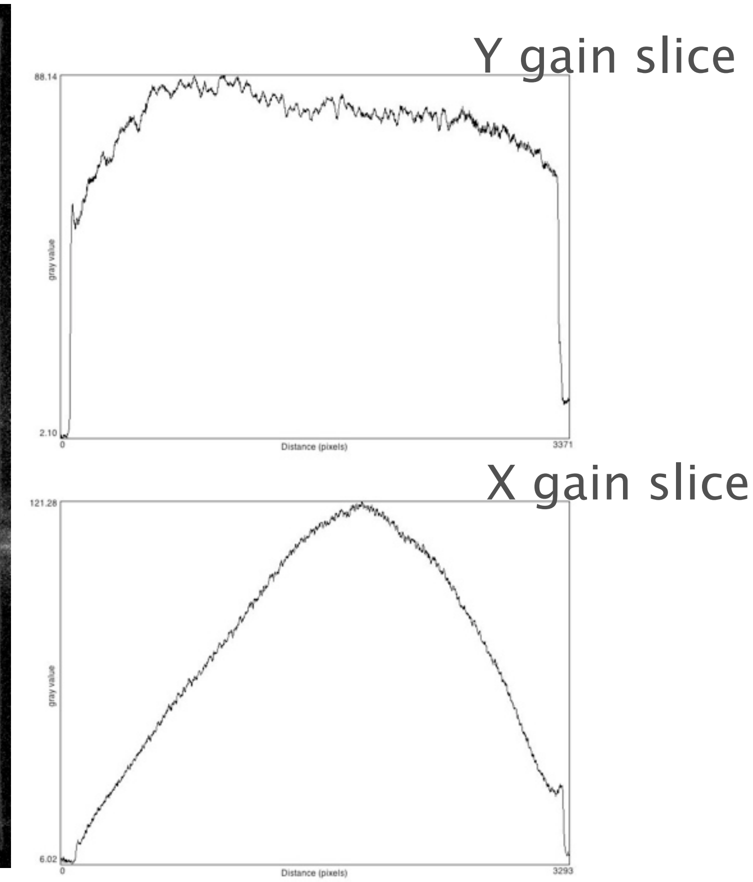
8” MCP Pair test at SSL

Top MCP
Bias direction

Bottom MCP
Bias direction

1. **Routinely producing targeted resistance**
2. **Emphasis now on SEE layer gain uniformity**



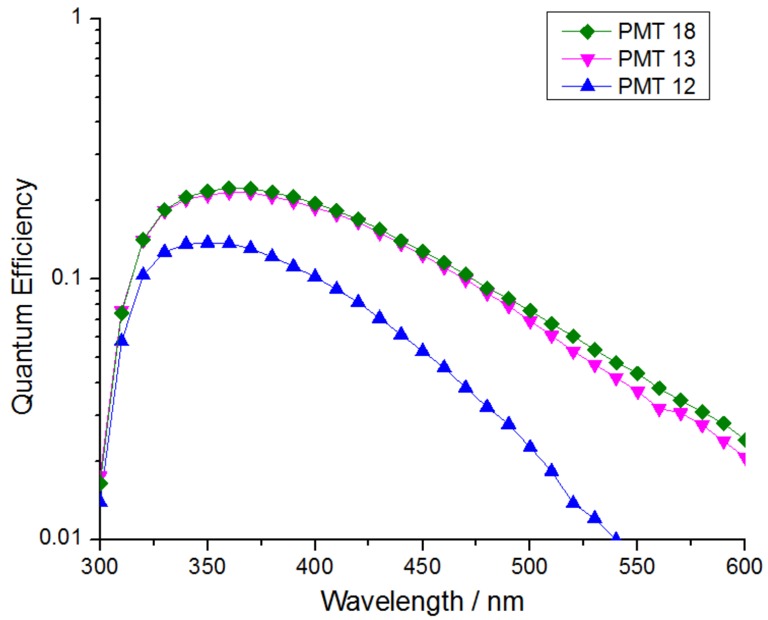


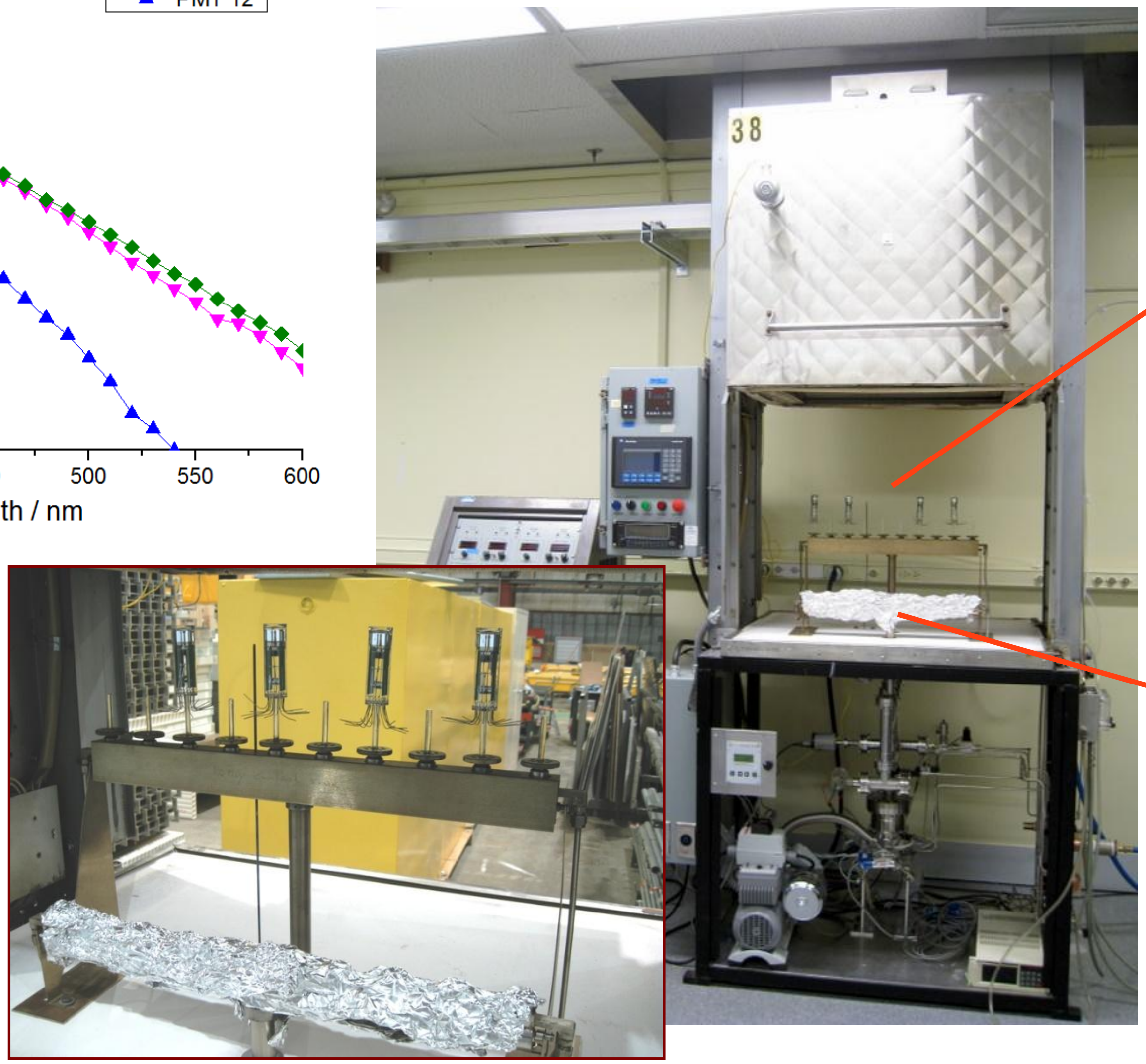
Areas of Future Focus for MCP Development

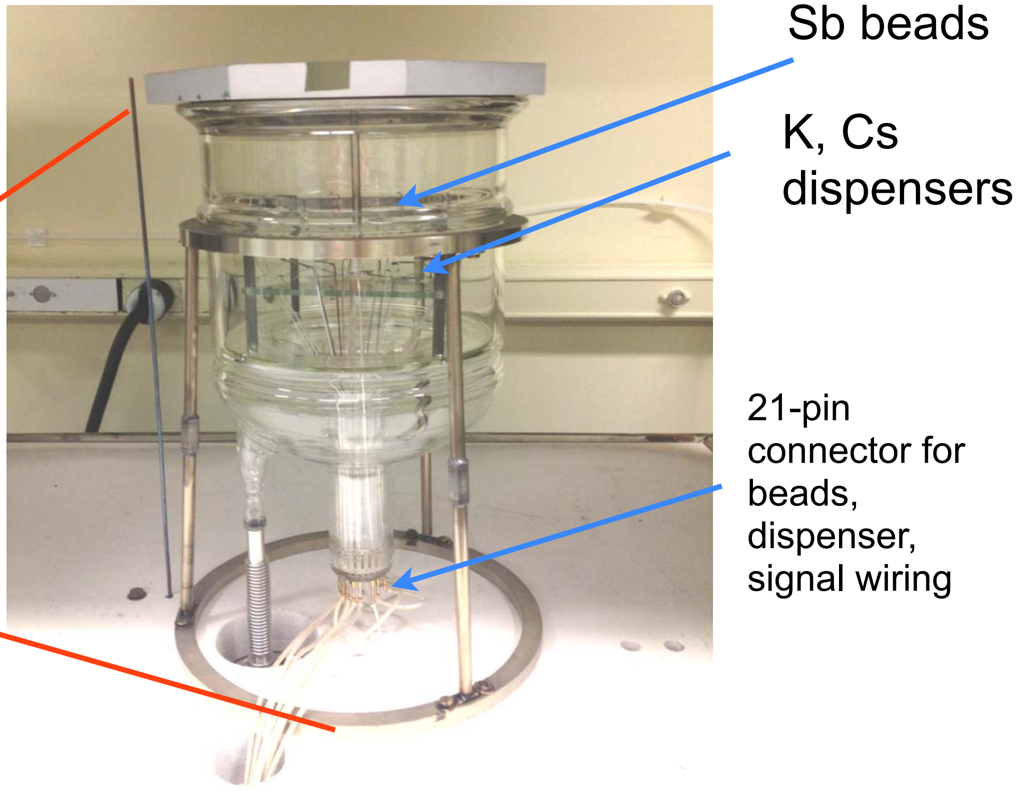
- **Near term:**
  - **Tune ALD processing for uniform gain**
  - **Produce 8” functionalized plates for sealed detectors**
- **3 Year Plans:**
  - **Explore new ALD chemistries for lower cost, higher rate**
  - **Refine ALD coating for higher throughput**
  - **ALD functionalization technology transfer to industry**

gain meas.: Ossy Siegmund & Jason McPhate, SSL

Photocathode Development — Argonne





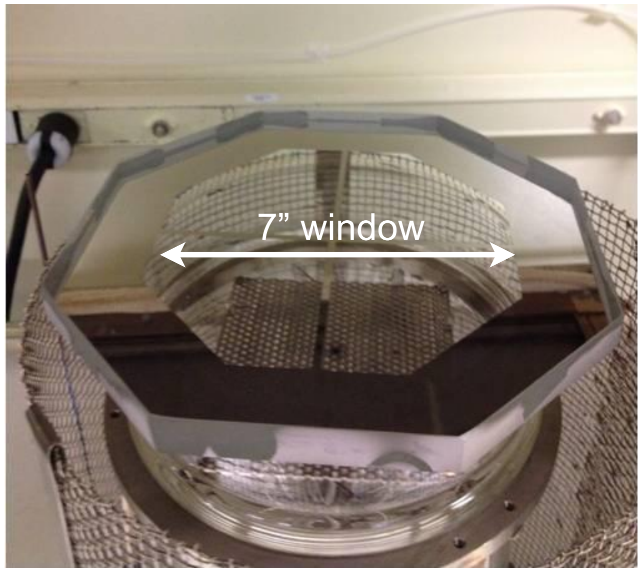


Large glass vacuum vessel (**Chalice**) replaced small PMT manifold to produce 4" & 7" photocathodes

Learned photocathode fabrication techniques on phototube process system purchased from Burle

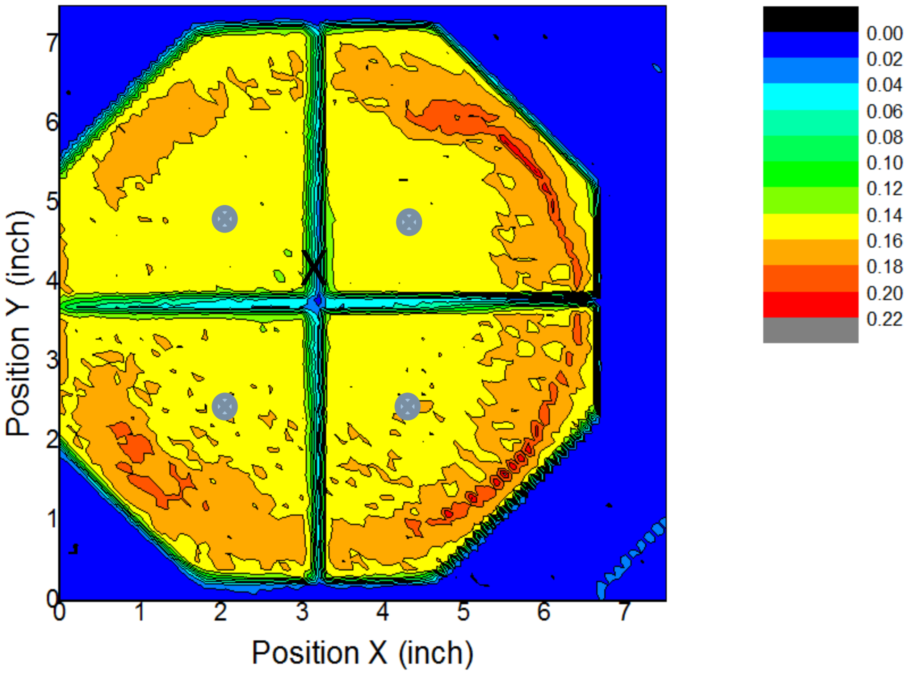
Developing techniques to scale to 8" transfer cathode for Tile Facility at Argonne

Scale-up to 7” Photocathodes at Argonne



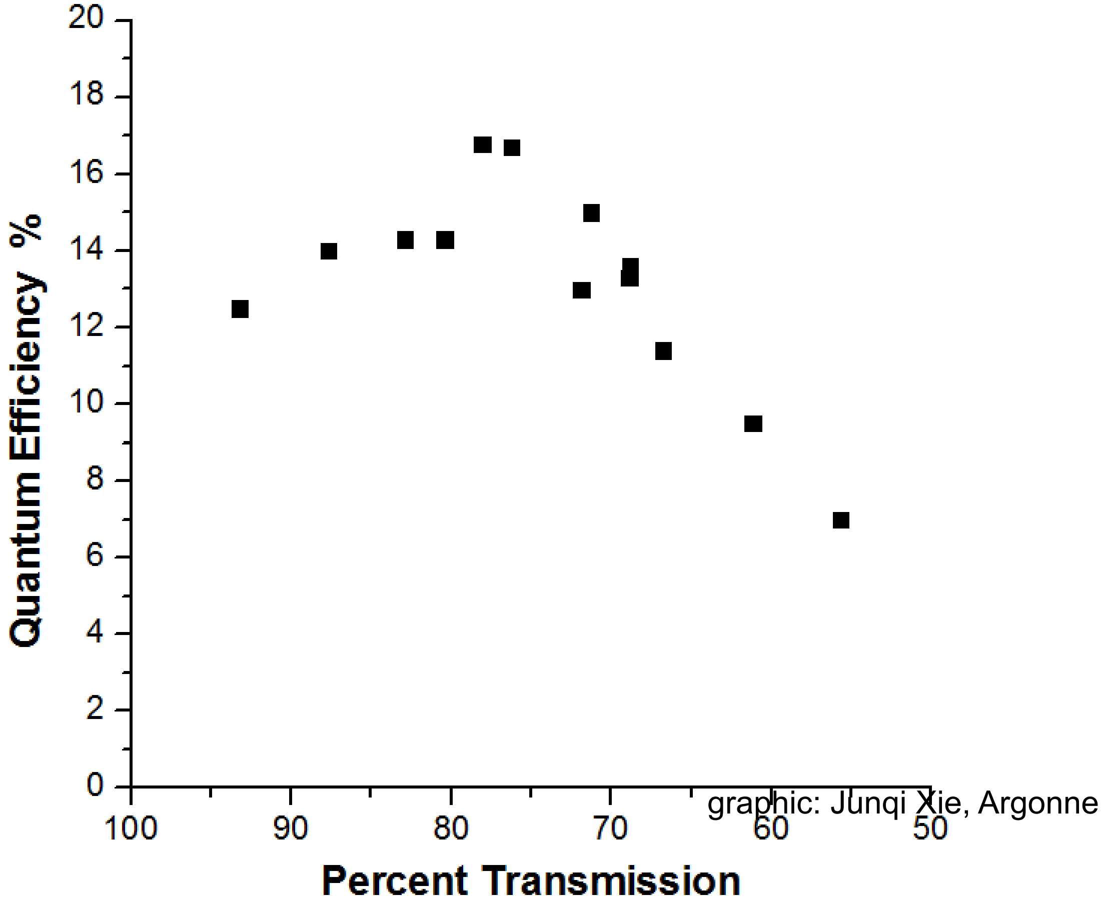
13 Photocathode shoots on “erasable” glass window:
- Tune process parameters
- Optimal # and placement of Sb, K, Cs dispensers
- Improve QE and uniformity

QE Map



Chalice Photocathode #9

KCs-Sb Photocathode

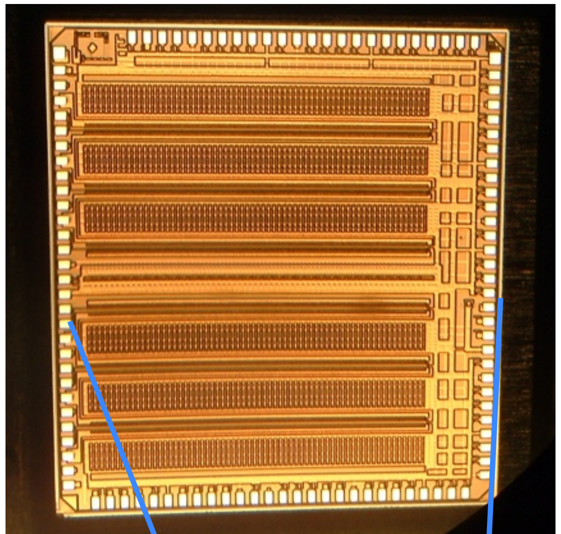


Optimization of QE w.r.t SB thickness
% transmission of Sb ⇒ thickness

- **Photocathode fabrication established at Argonne**
- **Ongoing study for uniformity and QE>20%**

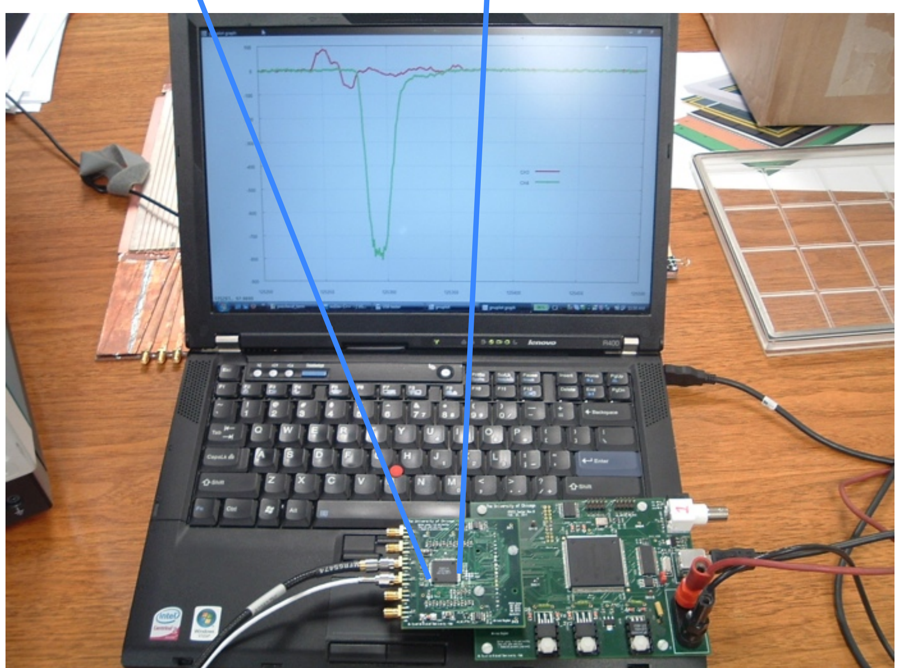
- **Future:**
  - **transfer techniques from Chalice to 8” tube processing system at Argonne**
  - **Collaboration with SSL, BNL, UChicago, WashU, … on understanding and improving photocathode QE**

Development & Testing of Front-end Electronics

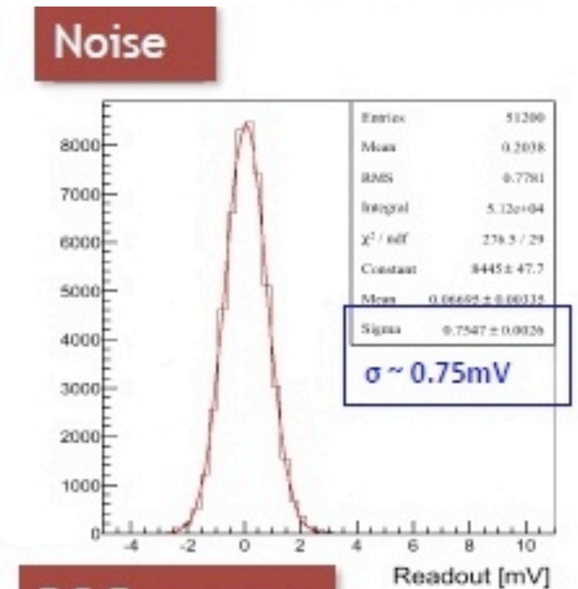


PSEC4 6-ch.
“scope-on-a-chip”
1.6 GHz BW, 10-15 GSa/s,
130nm technology

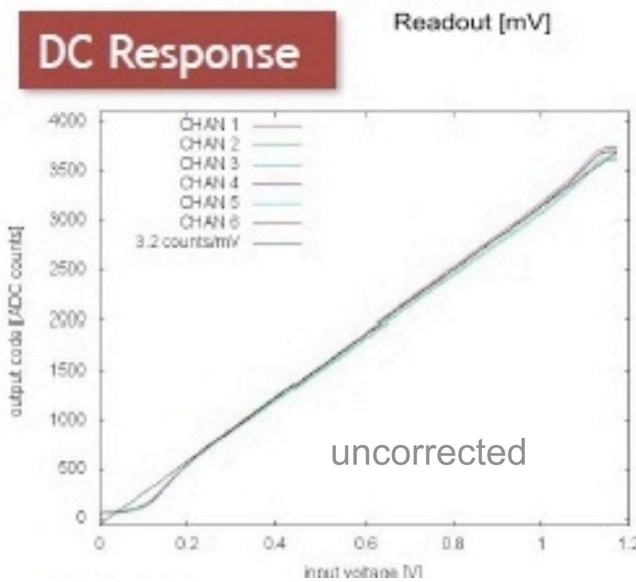
PSEC ASIC Design and Testing by
Univ. of Chicago & Univ. of Hawaii

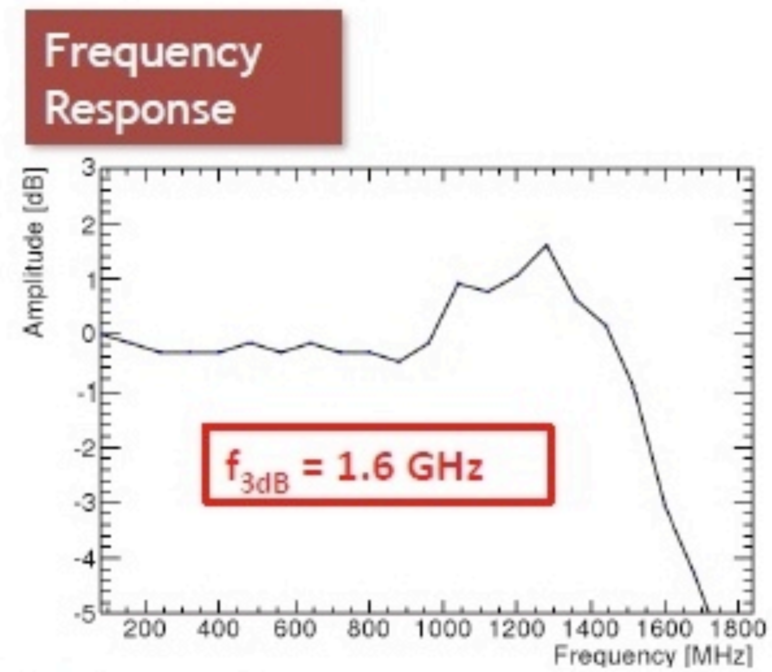


Evaluation board w/2.0 USB
interface + PC DAQ software



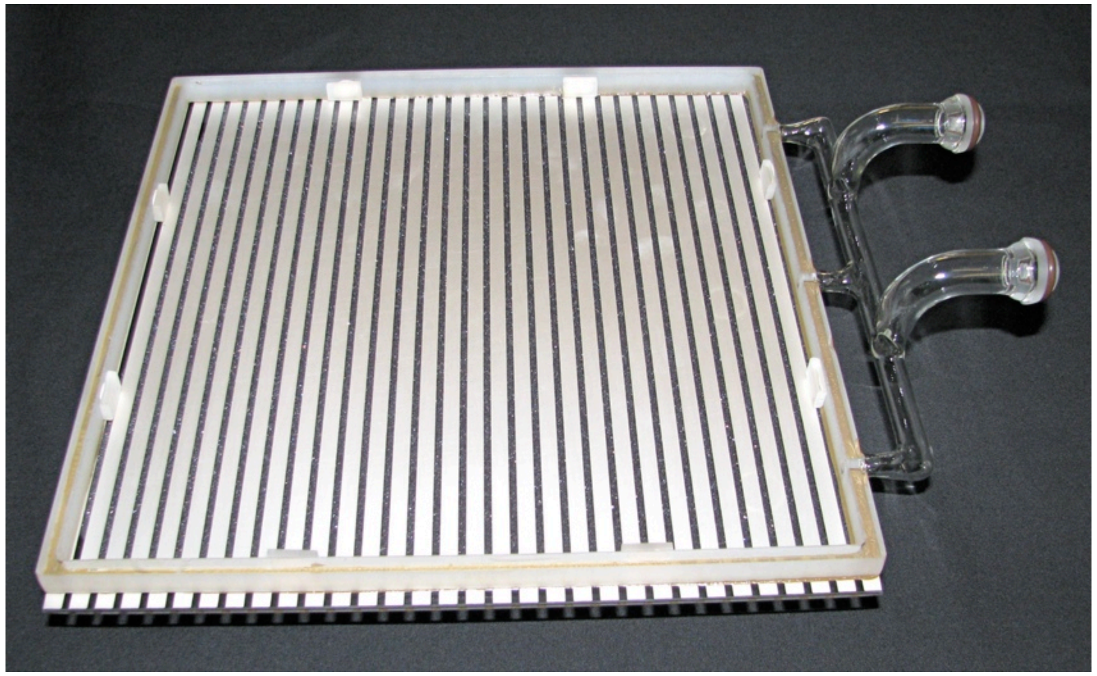
- Low noise <1 mV
- ~1V dynamic range with excellent linearity
- Analog bandwidth of 1.6 GHz
- Sampling rates up to 15 GSa/s



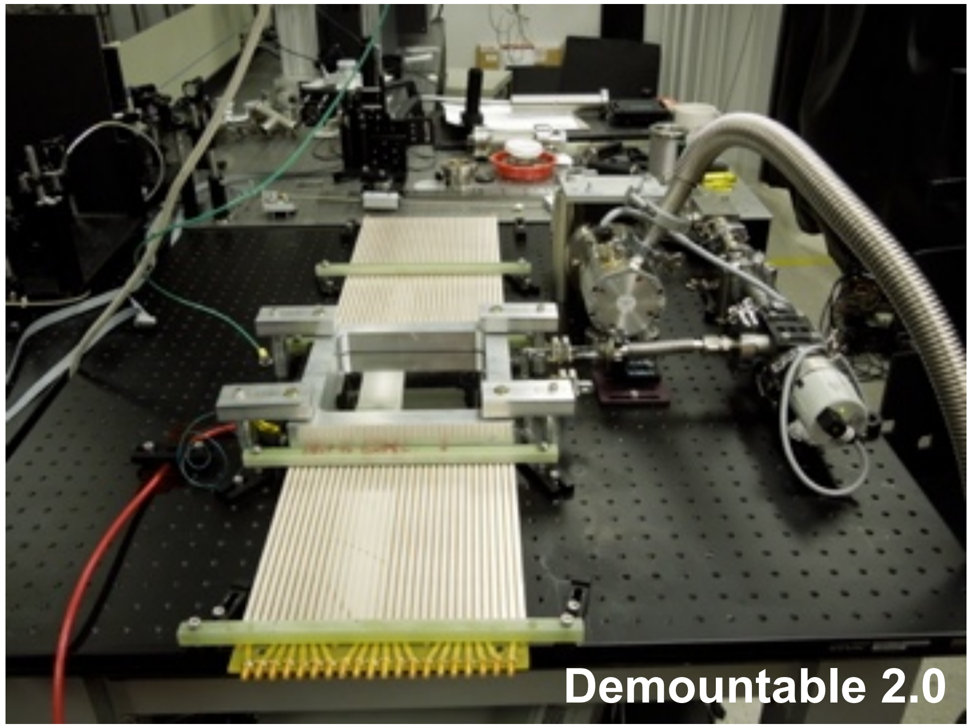


PSEC 4 design & test results: Eric Oberla
& Hervé Grabas, Chicago

Glass MCP Phototube Strip Line Anode

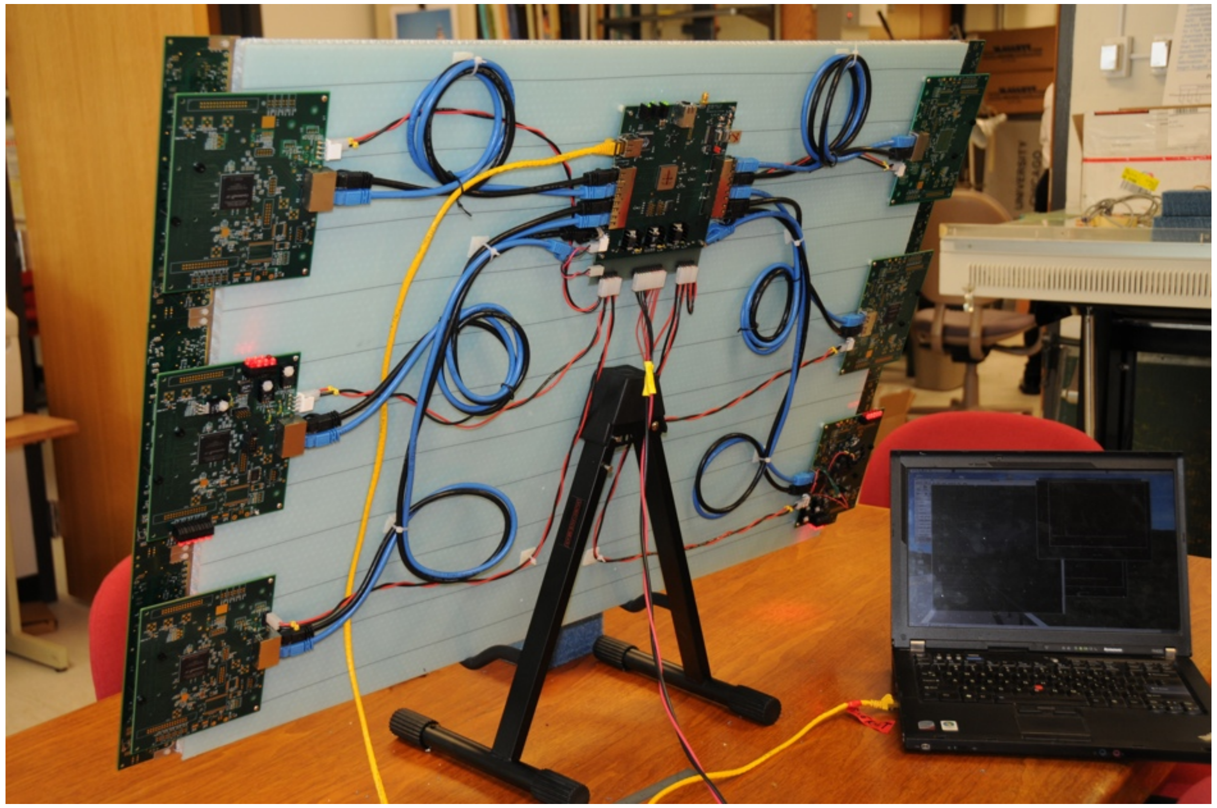


Tile base is 30 strip silk-screened anode



Digital & Central DAQ Boards: Mircea Bogadan & Craig Harabedian, Chicago

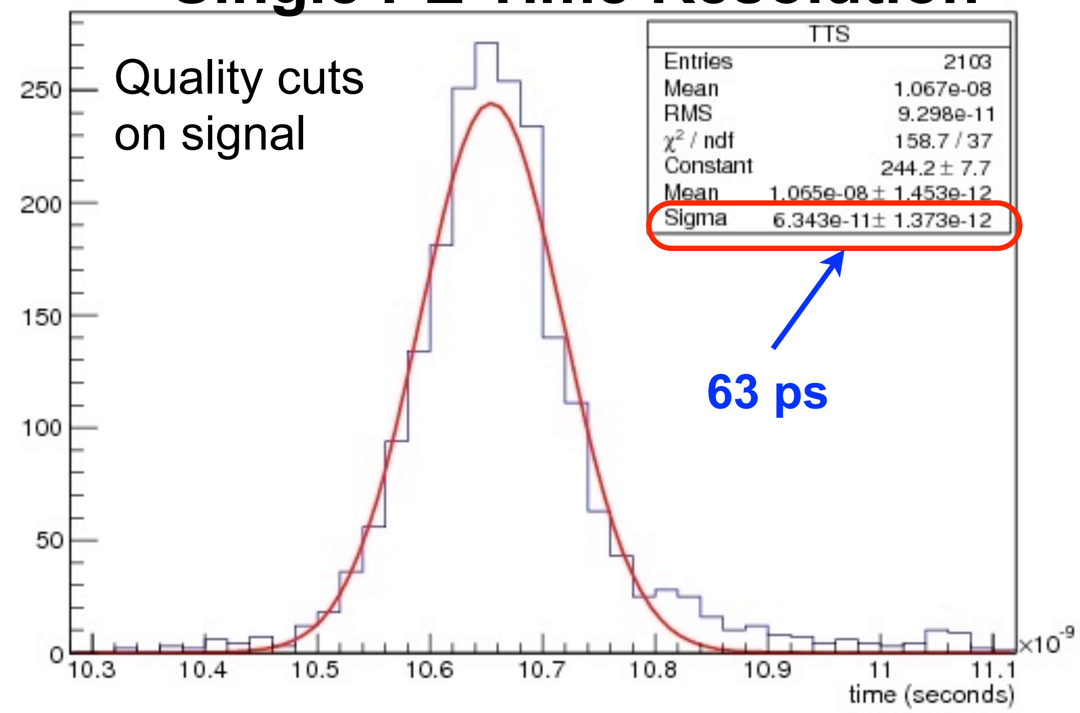
Tray and Tiles — The Super Module System



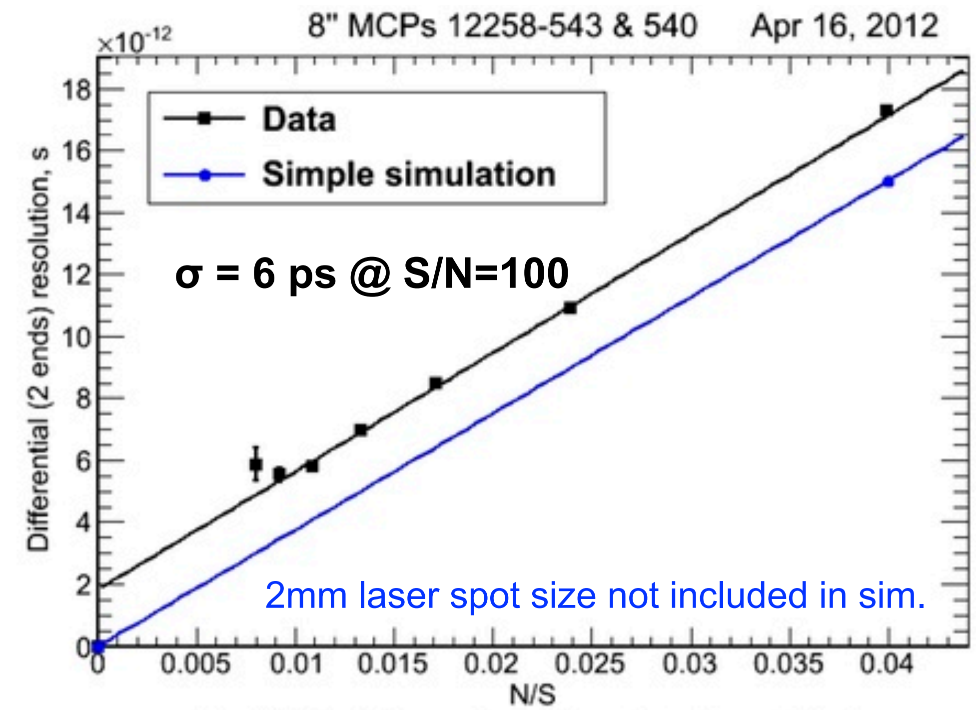
- One 8” MCP Glass PMT ≡ Tile
- Serial connection of tiles with common double-end readout minimally affects performance
- 4×3 array of tiles ≡ SuperModule Tray
- Complete readout chain from front-end waveform sampling ASIC through digital and central control cards to graphics processor PC has been integrated into SuperModule

Strip Line Anode Performance with 8” MCP Pairs

Single PE Time Resolution



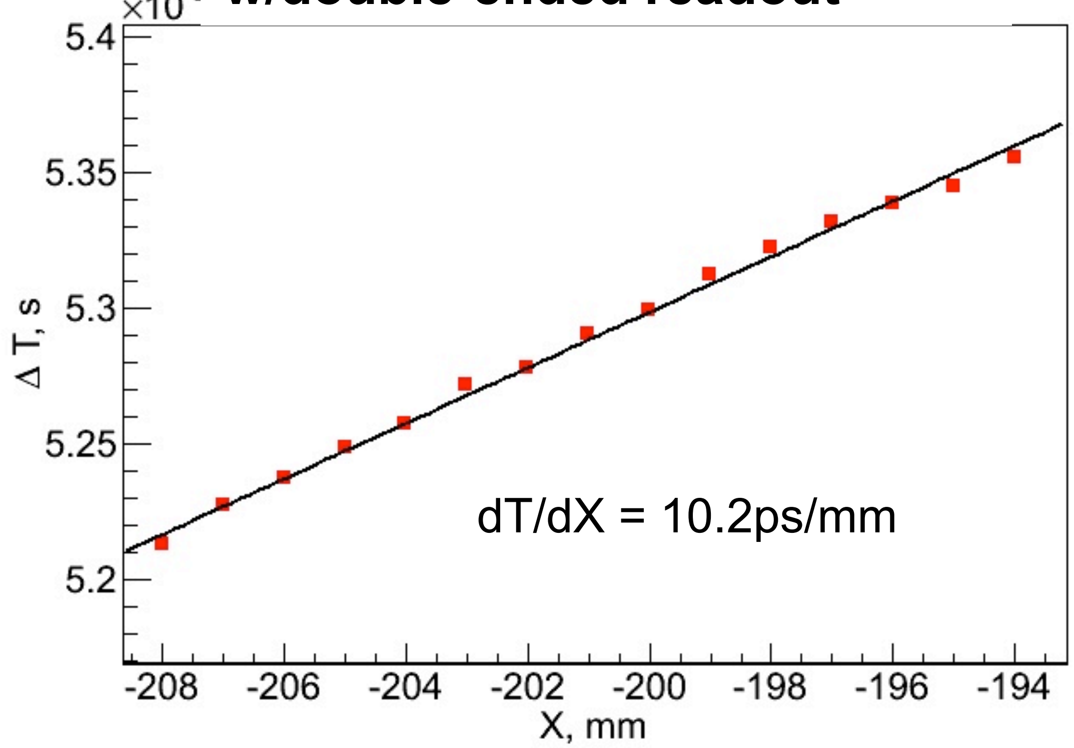
Differential Time Resolution vs. Noise



N = RMS of the noise; S = signal amplitude

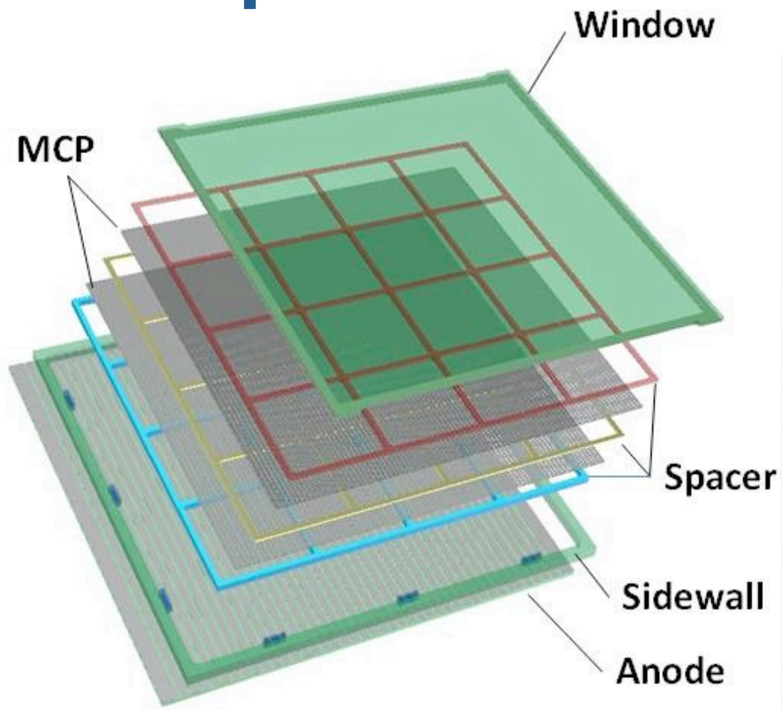
Simulation has many more points than shown. All are very well consistent with the blue line.

Position scan along stripline w/double-ended readout

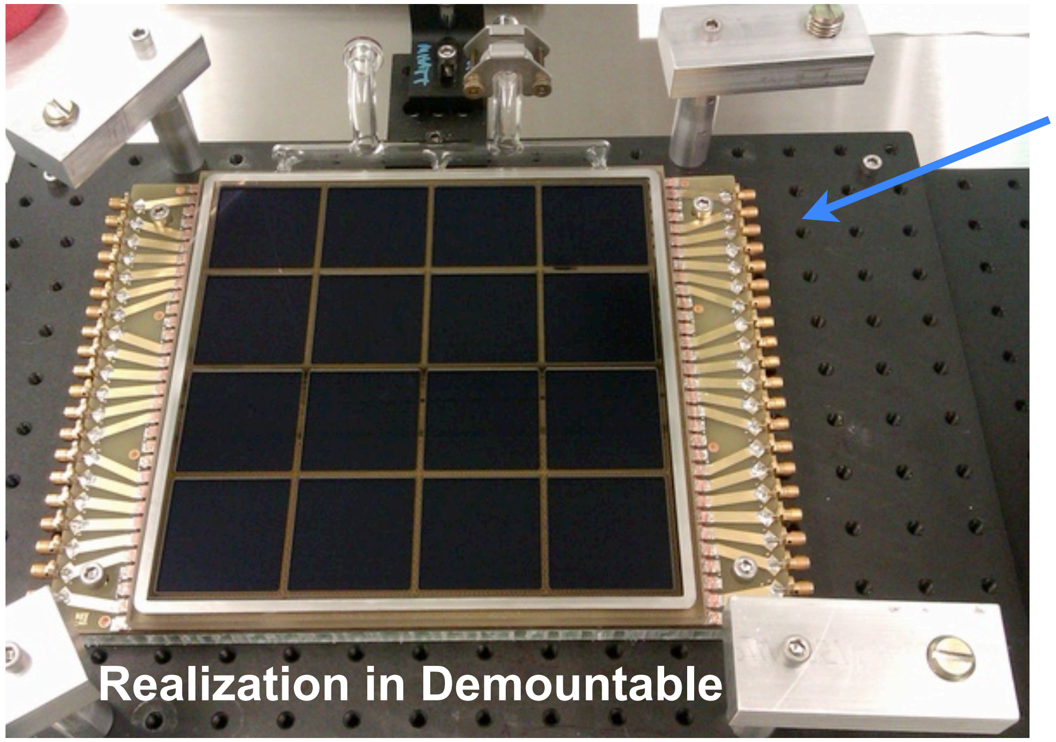


- Results from Argonne 8” Test Ch. w/UV laser excitation, fast scope readout (M.Wetstein, B. Adams, A. Elagin, R. Obaid, A. Vostrikov)
- Un-optimized Anode performance impressive and meets present needs
- Prospects for improvement to few ps resolution are good

Development of Hermetic Package – All Glass Tile



Design Drawing - September 2010

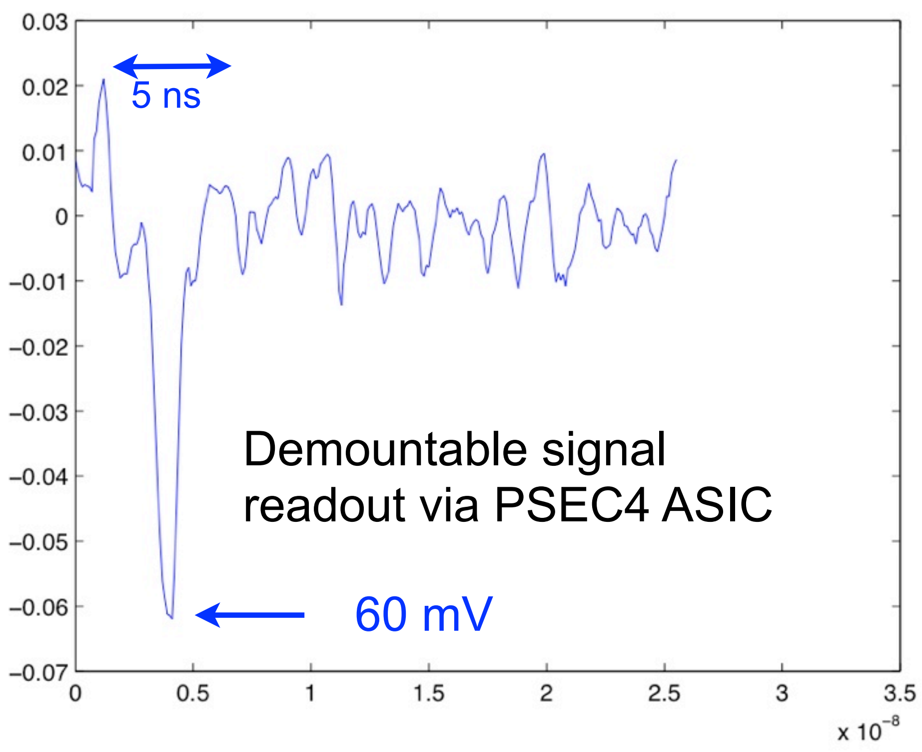


Assembled in ALD Lab Clean Room

Transported to APS UV Laser Test Setup

Demountable is o-ring sealed tile:

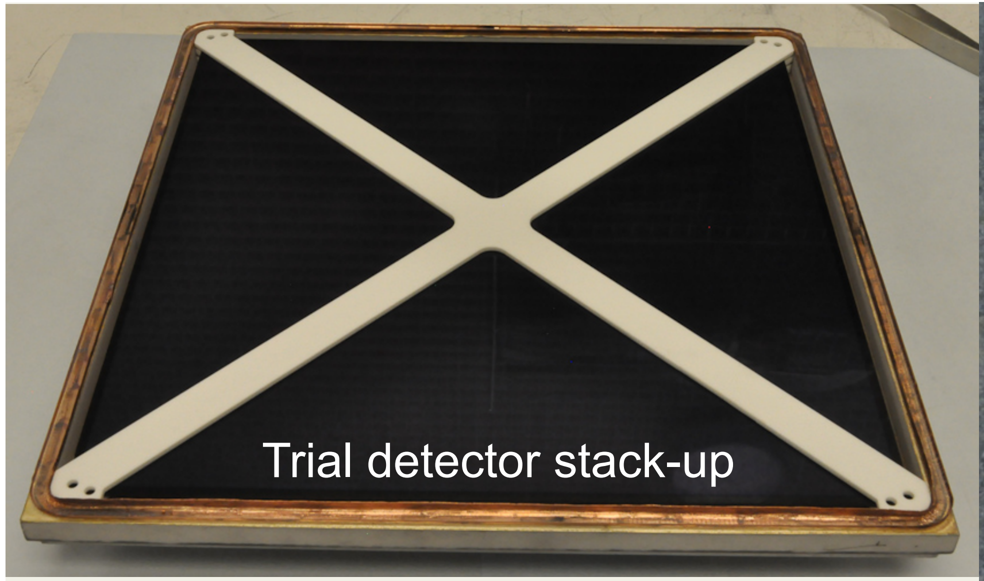
- Continuously pumped sealed tile with 8” MCP pair
- Al photocathode on quartz window
- ALD grid spacer for HV distribution
- 30-strip anode to fanout board



Future Work:

- **Complete work presently ongoing for Indium pressure seal for top window**
- **Produce smaller format sealed tiles in existing vacuum transfer system**
- **Produce sealed tiles with bialkali PC in future Argonne Single Tile Processing System**

Development of Hermetic Packaging — Ceramic Tube



- Process tank in commissioning
  - readying for 1st photocathode shoot in process tank; several 8” done in separate test chamber
- In/Bi seal tests in 8” test chamber
- Tile base braze progressing; ready for 3rd/final iteration
- On track for sealed tube this Fall

LAPPD Future Directions

- **SBIR/STTR:** At least 5 Letters of Intent from industry for 2013 FOA
  - Fully integrated sealed detector devices – STTR
  - MCPs for improved spatial/time resolution
  - Theory-based high QE photocathode development
  - Non-vacuum transfer process for production of MCP-PMTs
  - PET camera development
- **Tasks Requested for KA15 funding:**
  - All-Glass Tile Fabrication at Argonne (eventually several 10s per year)
    - Small format (<4” sq.) with modification of existing vacuum transfer system
    - 8” Single Tile Processing System
    - Rationale: Glass tubes for distribution to HEP community; MCP, ALD, photocathode development testing, alternative formats
  - Ceramic Tile Fabrication at SSL (5-6 per year
    - Improve design and throughput
    - Improved QE
    - All-glass fabrication in SSL process tank
  - Generation II R&D (Argonne, UChicago, SSL, UHawaii)
    - Improved MCPs, photocathode, readout

Existing 4” Vacuum Transfer System at Argonne – System for Early Vetting of STF Process

Two chamber CsTe Photocathode Transfer System

Indium Top Seal Vacuum Test Chamber

Possible early STF demonstrator:

- Chambers can be coupled via existing 6” flanges to give PC process chamber and sealing chamber.
- Left system is operating now at 5×10^{-10} torr, right system is 10^{-8} torr
- Photocathode Transfer System will be moved to Bldg. 360 in September

LAPPD Project Summary

Capability Gap

- Existing MCPs have small effective area, are expensive, and have all properties embodied in a single medium.
- Development of large area MCP-PMTs with few ps resolution would provide a transformational tool for HEP experiments, e.g.
  - Water Č tracking detector
  - Higher momentum Particle ID
  - Pile-up vertex separation/Photon vertexing

Benefit

- Potential for picosecond time and millimeter spatial resolution photodetection over large surface areas.
- Applications within and beyond HEP.
- Re-establish U.S. photodetector development and manufacturing.
- Potential large cost savings for detectors requiring 1000s of photodetectors.

Approach

- MCP substrate, resistive, and emissive components separated into individually tunable materials.
- Less expensive borosilicate glass hermetic package
- Parallel ceramic body approach using proven techniques and expertise.
- Integrated DAQ w/Waveform Sampling ASIC frontend.
- Enabled by unique multi-disciplinary expertise and cross-divisional infrastructure at Argonne

Results and Future

- Signals from o-ring sealed complete all-glass MCP tile
- Diff. time resolution with 8" MCP pair < 6ps
- Complete DAQ system with PSEC4 ASIC; 15 GSa/s; noise<1mV, bandwidth ~1.6GHz
- 8" Photocathode QE~25% @ 350nm & uniform & stable
- On track for sealed ceramic MCP-PMT by Fall
- Propose to construct MCP Tile Facility at Argonne to produce all-glass tiles for evaluation by HEP community
- Continue production of ceramic tiles at SSL
- PC research to achieve QE » 25%
- Seek industrialization of photodetector through SBIR/STTR

Backup Slides

The Large Area Picosecond Photodetector Participants During the First 3 Years

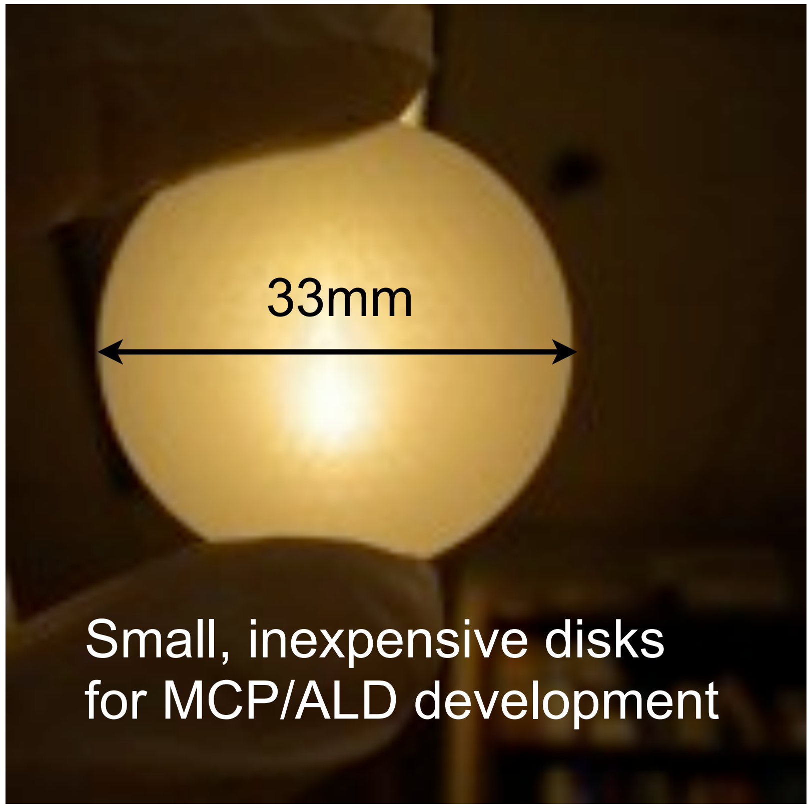
- National Labs
  - Argonne
    - HEP Division
    - Energy Systems Division
    - Nuclear Engineering Division
    - Glass Shop
    - X-ray Sciences Division
    - Materials Science Division
    - Mathematics and Computer Science Division
  - Fermilab
- Universities
  - University of Chicago
  - Space Sciences Lab/UC-Berkeley
  - University of Hawaii
  - Washington University
  - University of Illinois — Chicago
  - University of Illinois — Urbana/Champaign
- U.S. Companies
  - Incom, Inc.
  - Arradiance, Inc.
  - Synkera Technologies, Inc.
  - Minotech, Inc.
  - Muons, Inc.

LAPPD is a multi-disciplinary/multi-institutional effort that draws on the unique expertise and infrastructure at Argonne and at our partner institutions

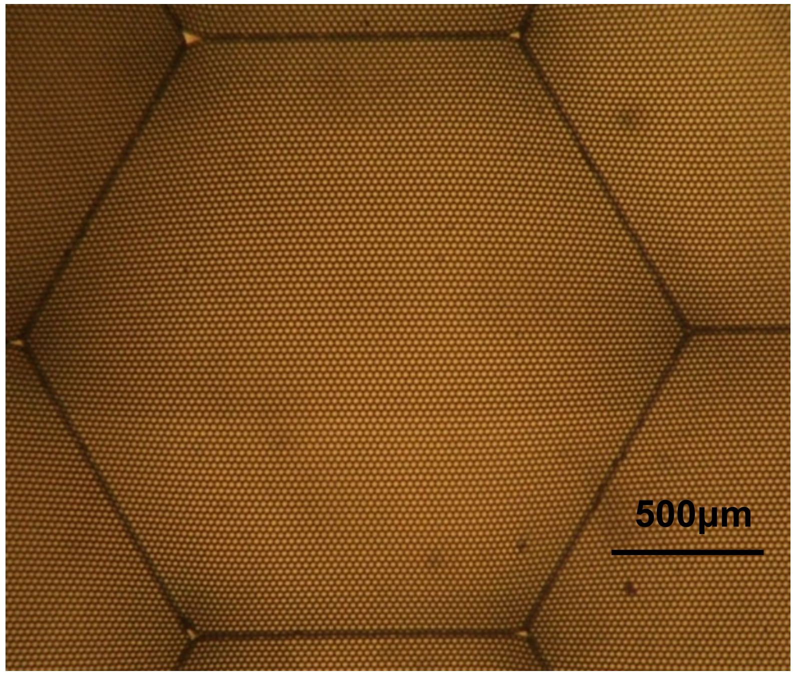
Development of Economical Borosilicate Capillary Arrays for MCPs — Industrial Partnership w/Incom, Inc

Fused block ready for slicing

Small, inexpensive disks for MCP/ALD development

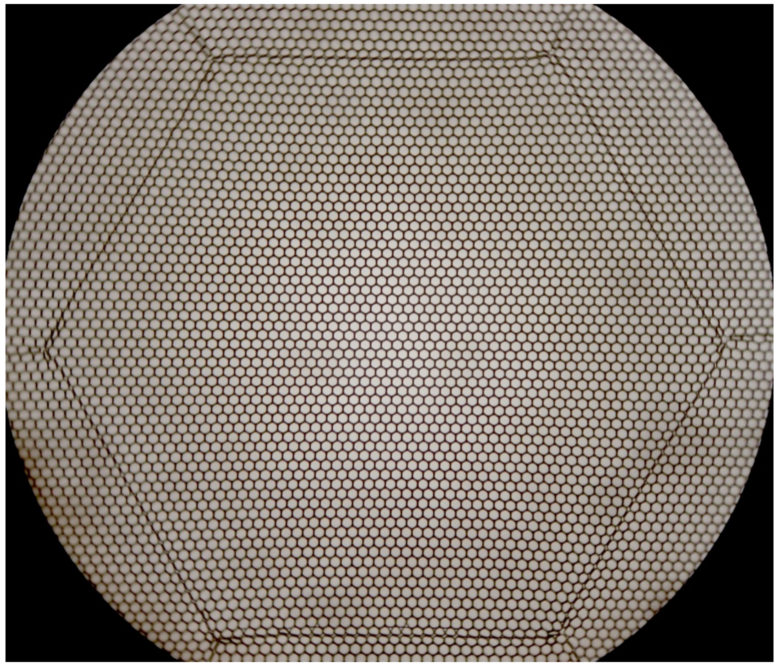


First block



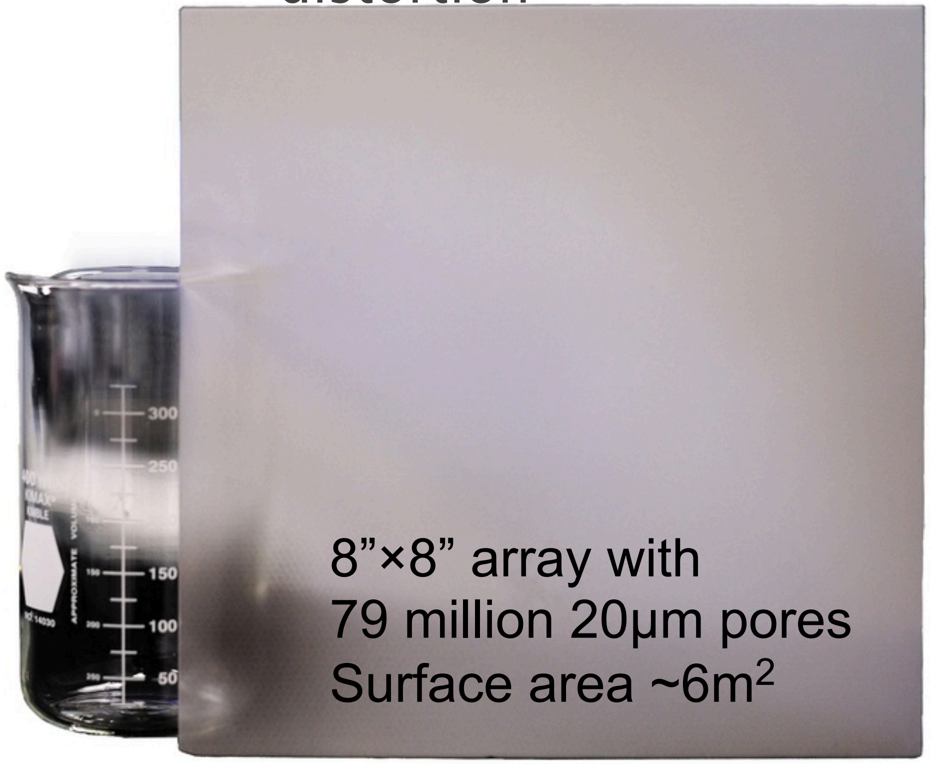
- Multifiber stacking
- Triple point gaps
- Pore crushing at multifiber boundaries

Most recent block



- Triple points mostly eliminated
- Minimal boundary pore distortion

Capillary array quality dramatically improved during last 2.5 years



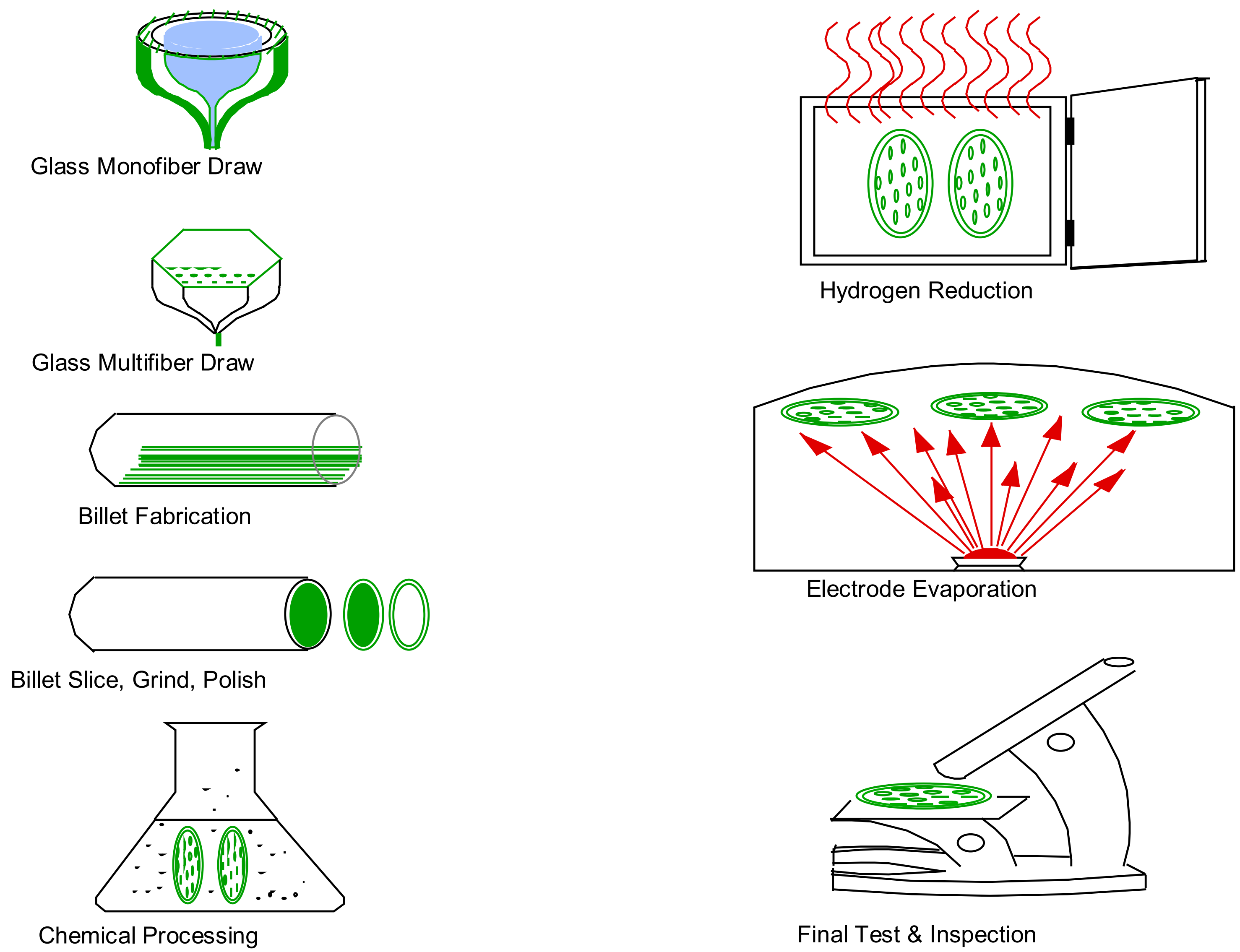
Industrial Microchannel Plate Fabrication

Graphic Credit: B. Laprade & R. Starcher, Burle (2001)

Glass is gravity-fed via cylindrical furnace

Glass is typically lead glass tube with solid soft glass core

Chemical processing to remove soft core glass

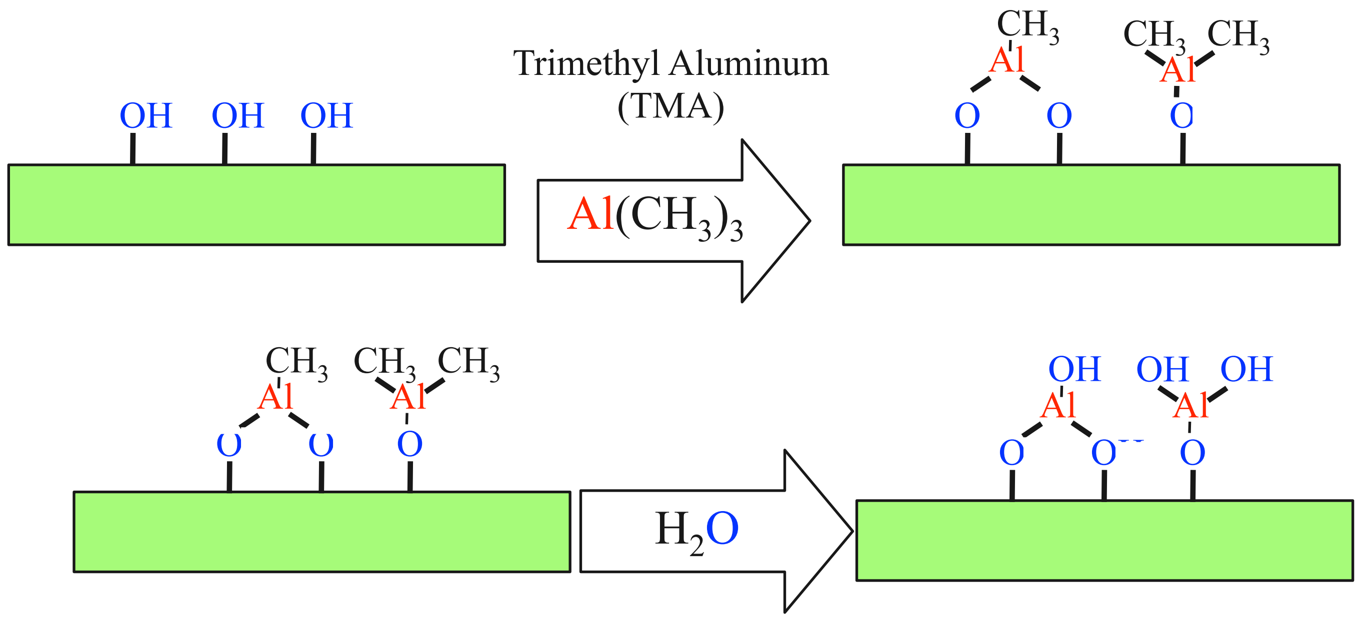


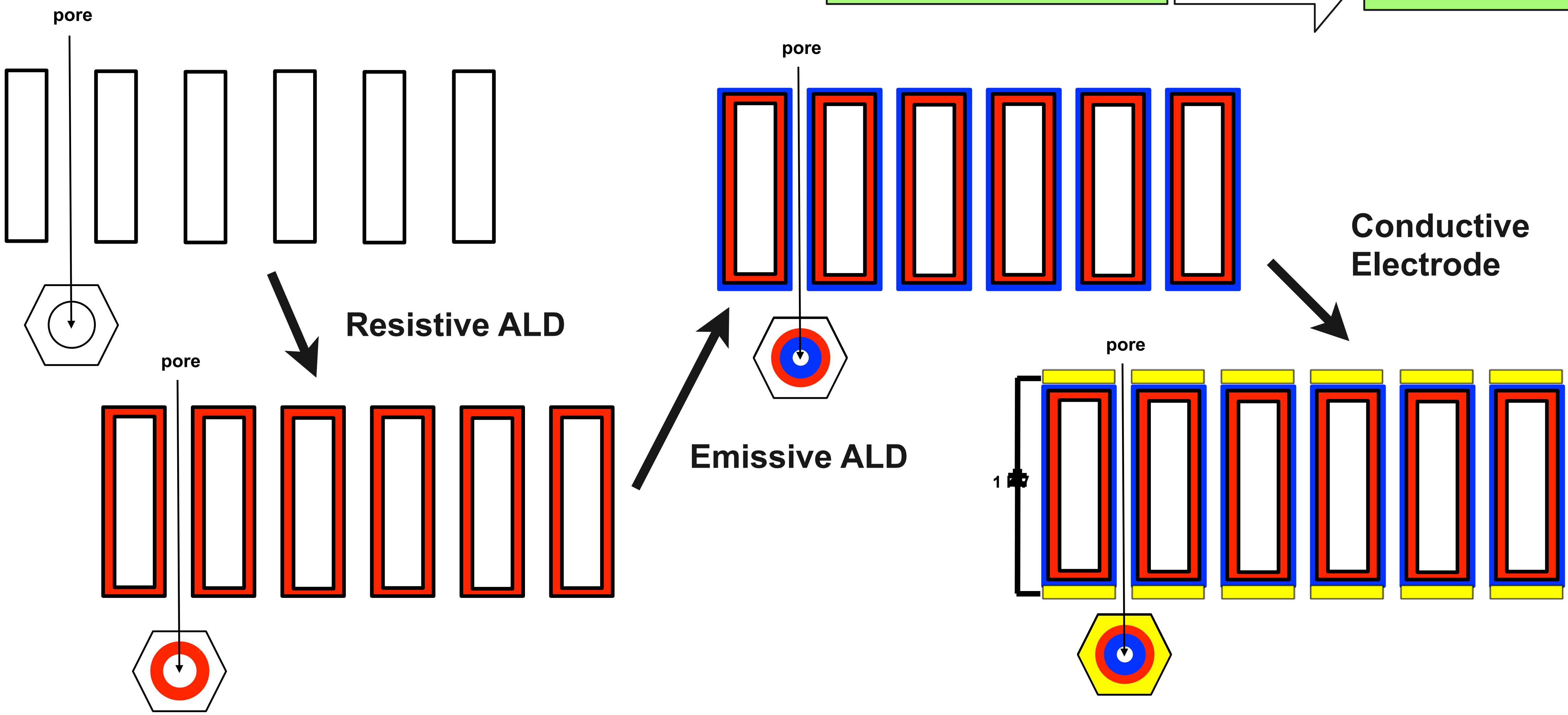
Before sealing in tube, plate must be subjected to prolonged exposure to electrons at low voltage to outgas H_2 and other material

Pore Activation via Atomic Layer Deposition (ALD)

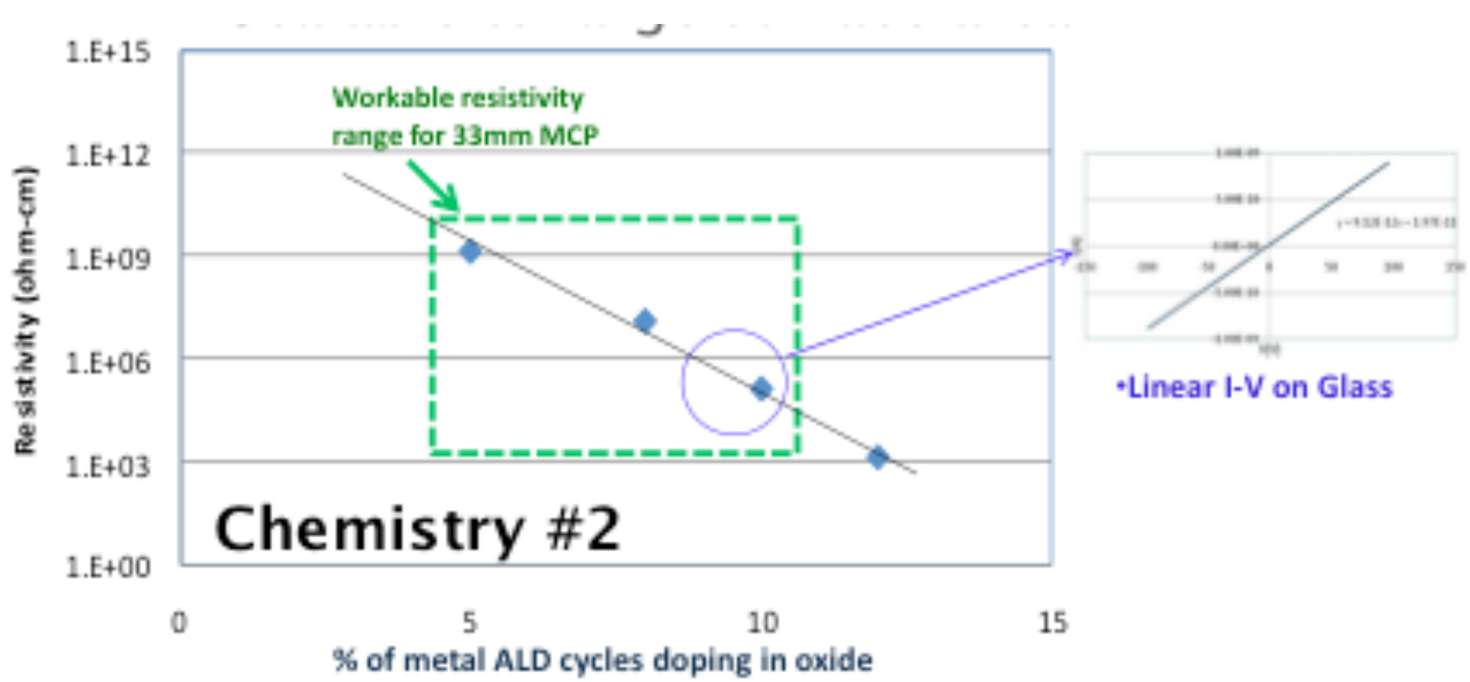
Example:

- OH on surface provide reaction sites
- Trimethyl aluminum reacts liberating methane, forms Al_2O_3 layer. Leaves methyl group inhibiting further reaction on surface
- Exposure to H_2O removes methyl group. Leaves OH sites for next reaction

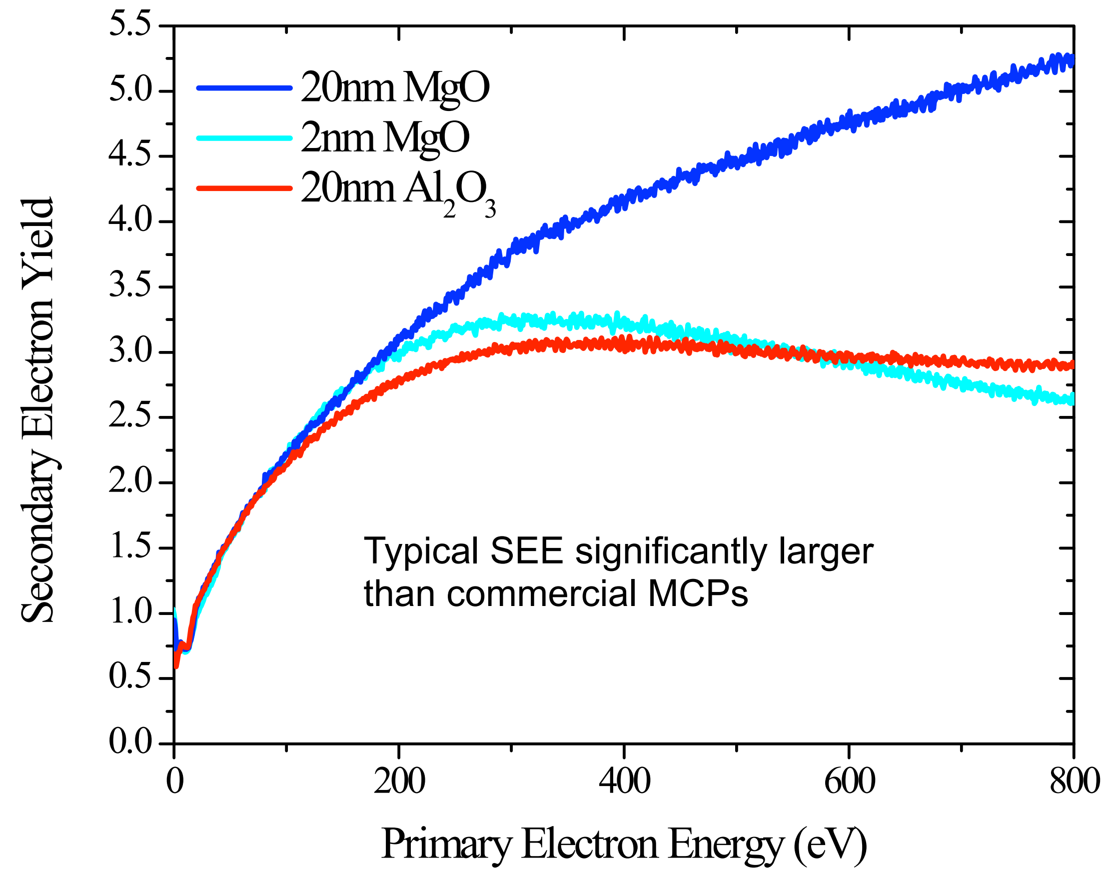




Materials Characterization

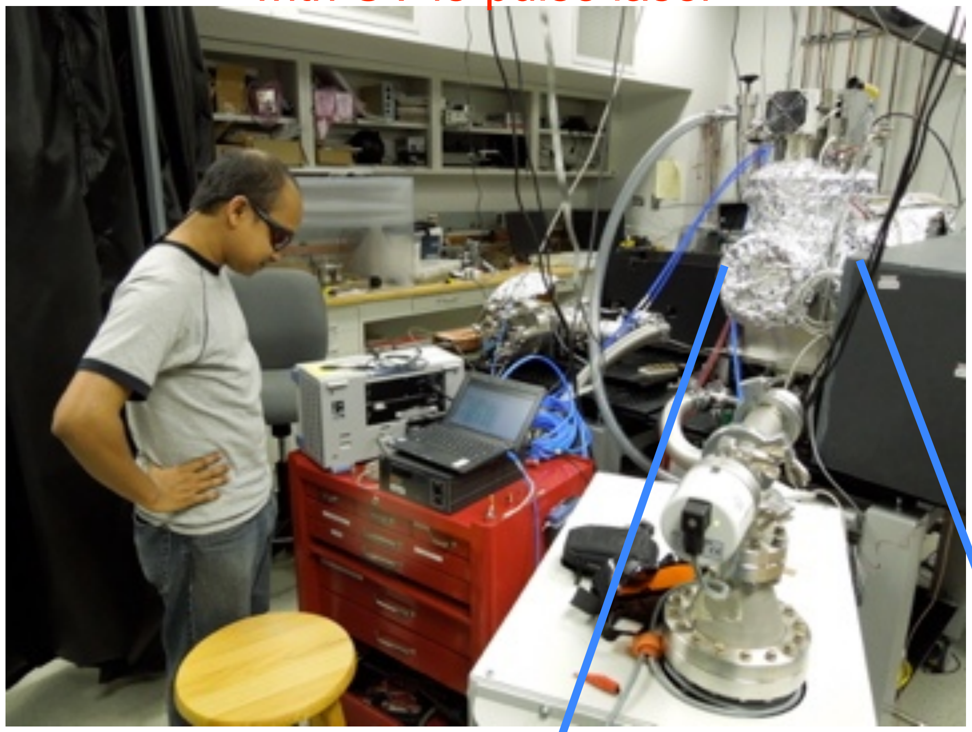


Secondary Emissive Materials characterized with Low Energy Electron Diffraction (LEED)



MCP Testing at Argonne and SSL — Facilities

Argonne 33mm & 8” Test Chambers
with UV fs-pulse laser

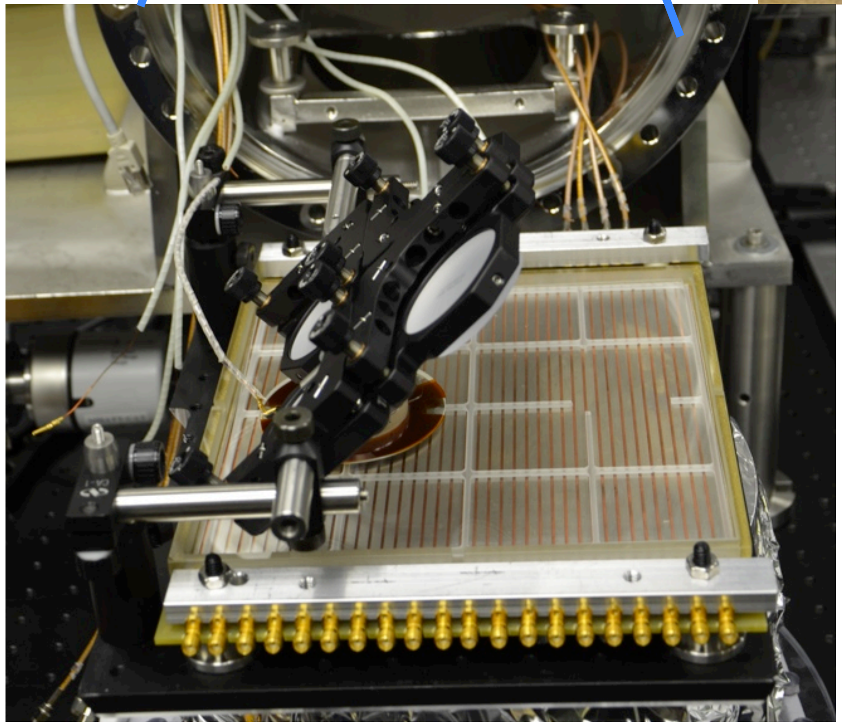


SSL 33mm Test Chambers

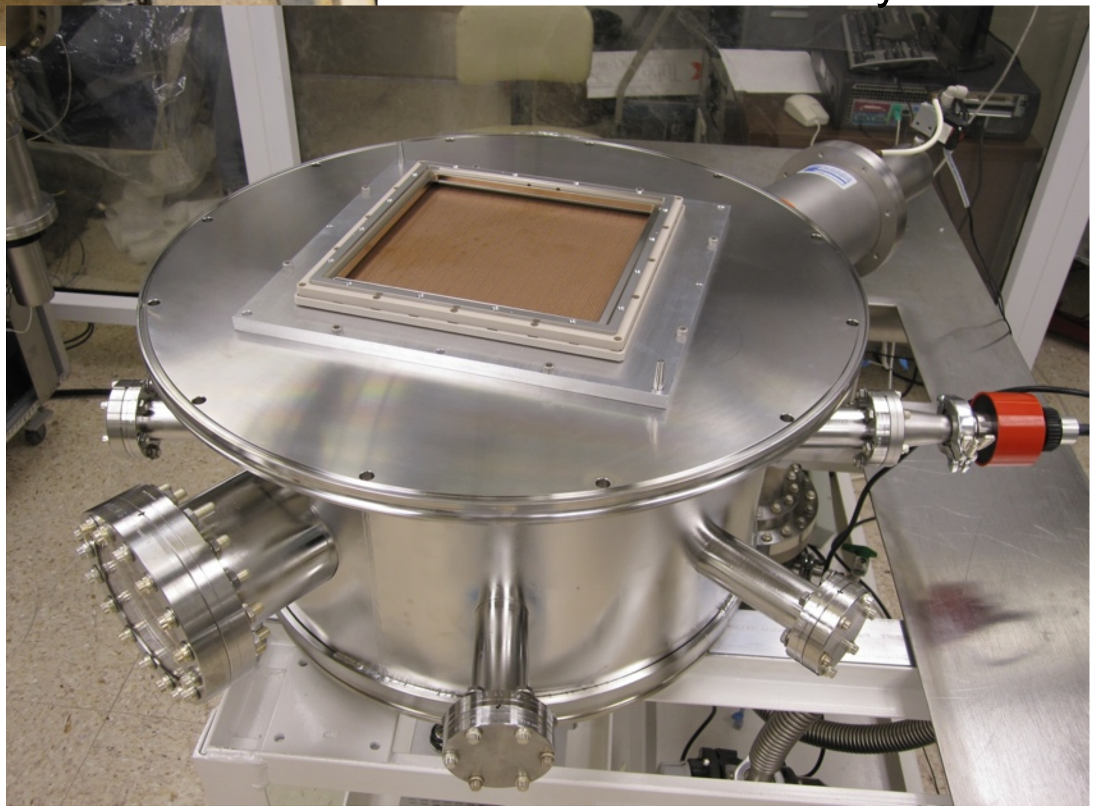
Phosphor detector on left imaged with camera

Cross-strip delay line on right for gain mapping

MCP on stripline anode ready for insertion into 8” chamber

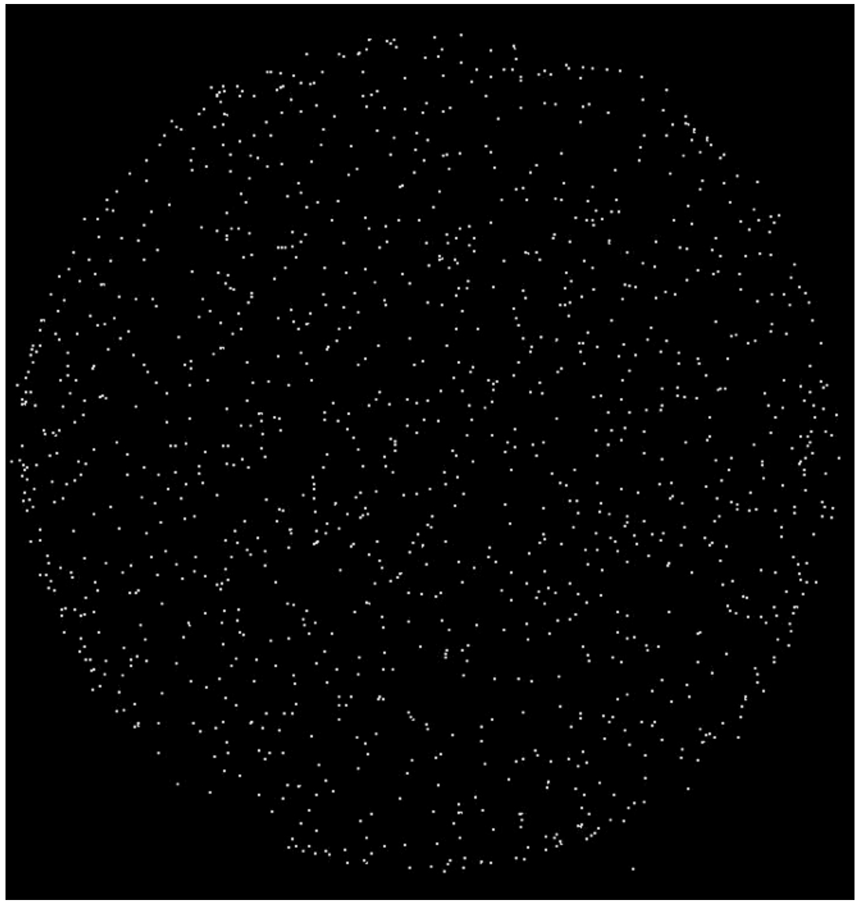


SSL 8” MCP Test Detector Vacuum System

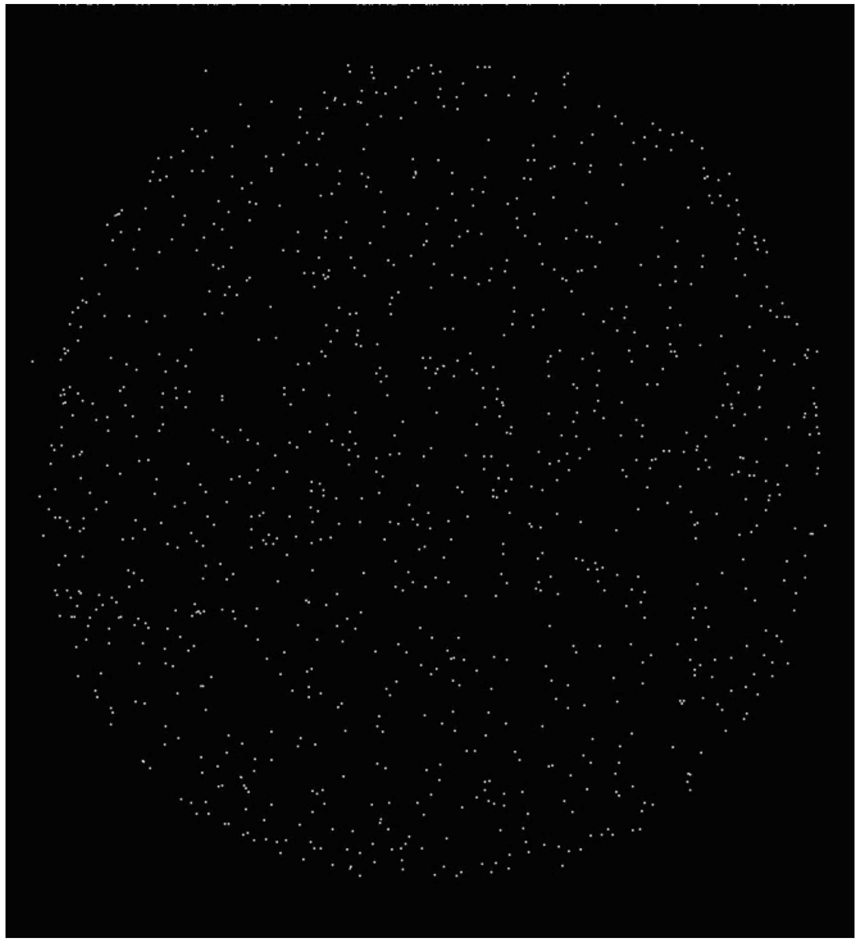


Noise Characterization

MgO SEE Layer



3000 sec background, 0.0845 events cm^{-2} sec^{-1} at 7 x 10^6 gain, 1025v bias on each MCP. Get same behavior for most of the current 20µm MCPs

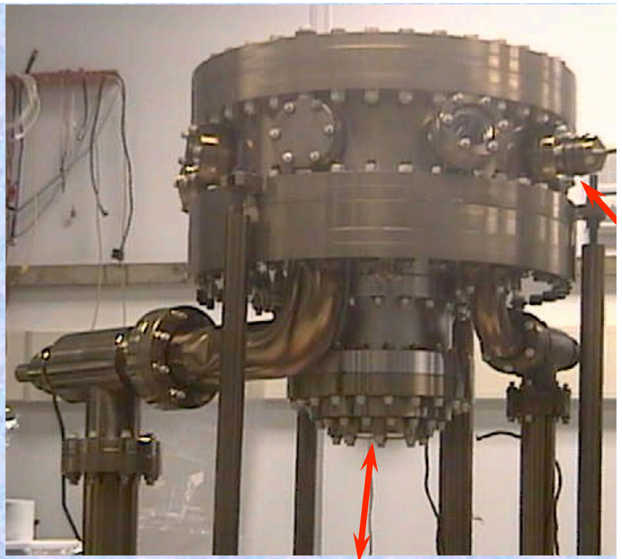


Post-bake –2000 sec
~0.1 events cm^{-2} sec^{-1}

8” Photocathode Development — SSL/Berkeley

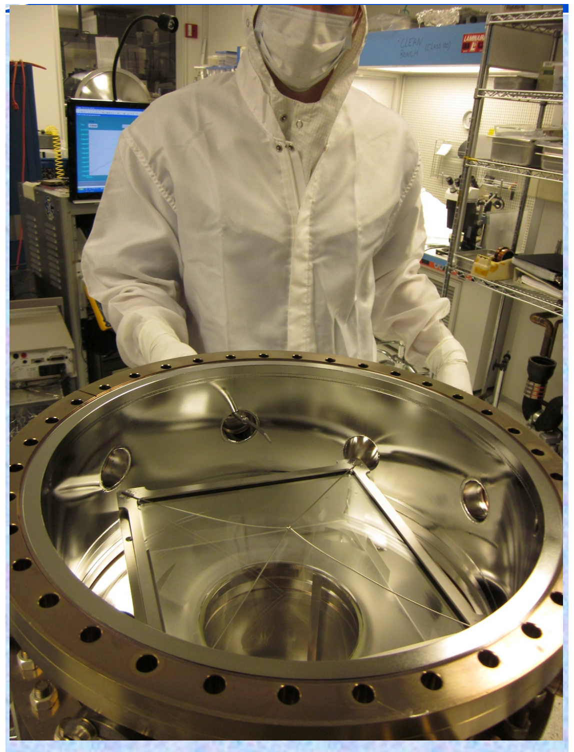
Na_2KSb Photocathode Chosen for

- Resistivity
- Noise
- Temperature robustness
- Uniformity



Alkali sources

Larger 16” flange tank, for testing
-Quantum efficiency
-QE Uniformity
-Seal tests

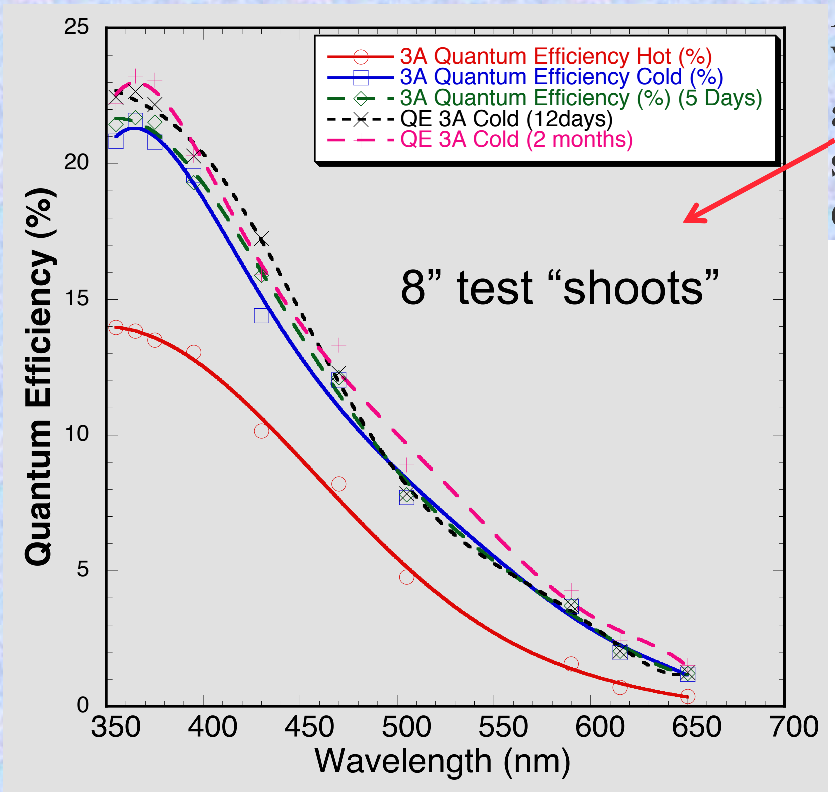


8.7” window loaded

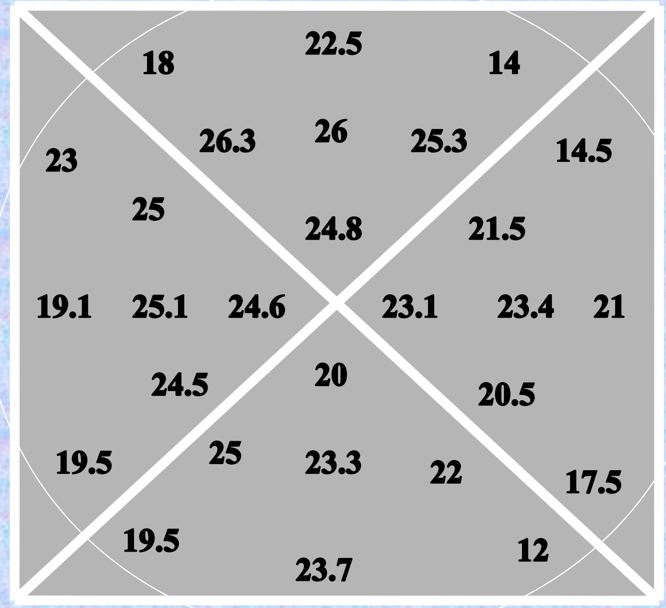
graphics: Ossy Siegmund & Jason McPhate, SSL

8” Photocathodes successfully produced at SSL

- **Cathodes in 8” test chamber with QE~25%**
- **Uniformity and stability meet MCP tube needs**
- **Ready to transfer techniques from 8” test ch. to large tube processing station.**

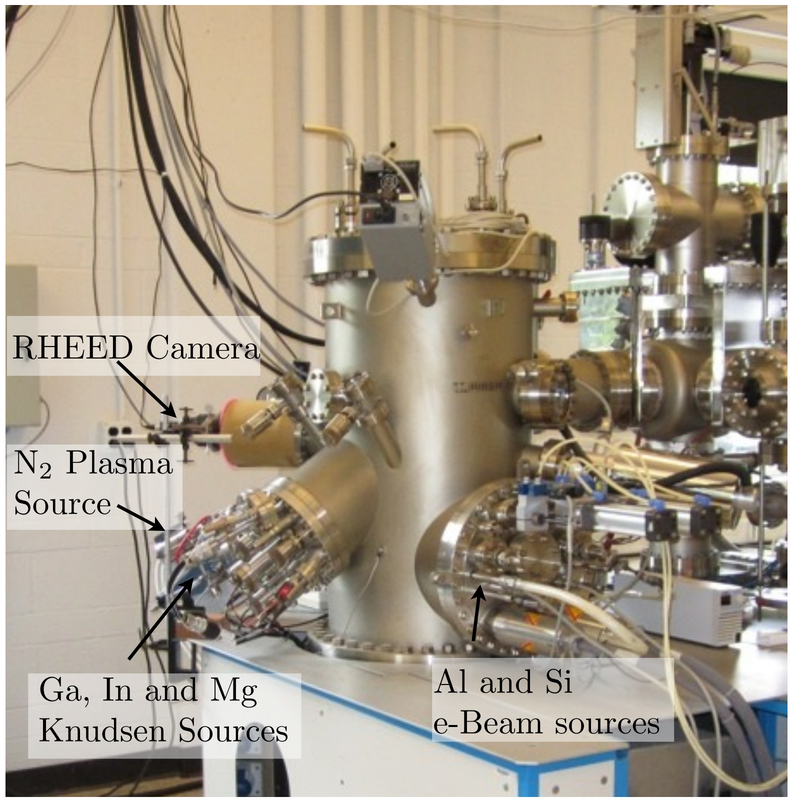


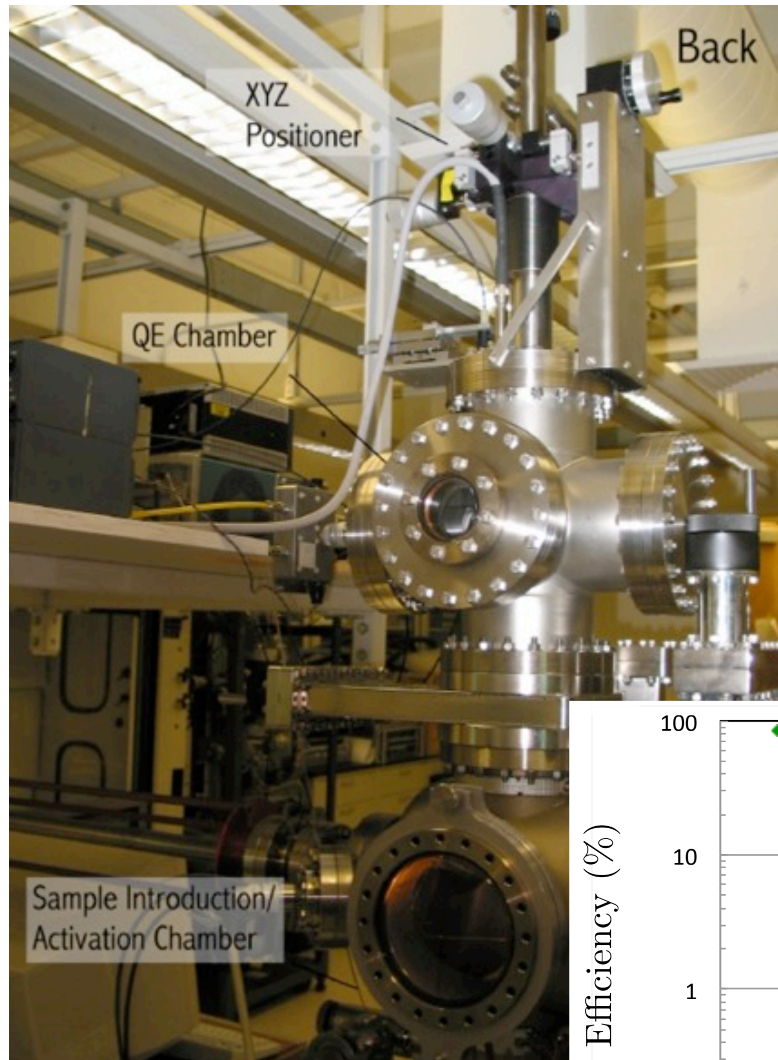
Basic process is a co-evap technique. We get an enhancement of the QE after cool-down. The QE has remained stable over the 2 months since deposition.

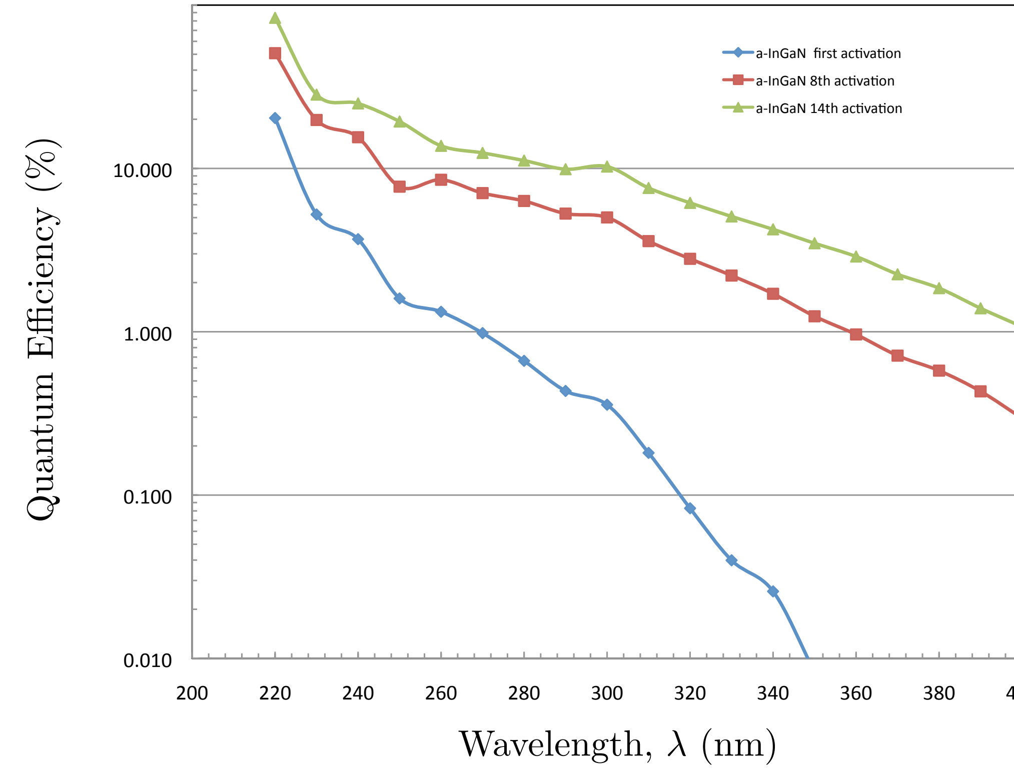


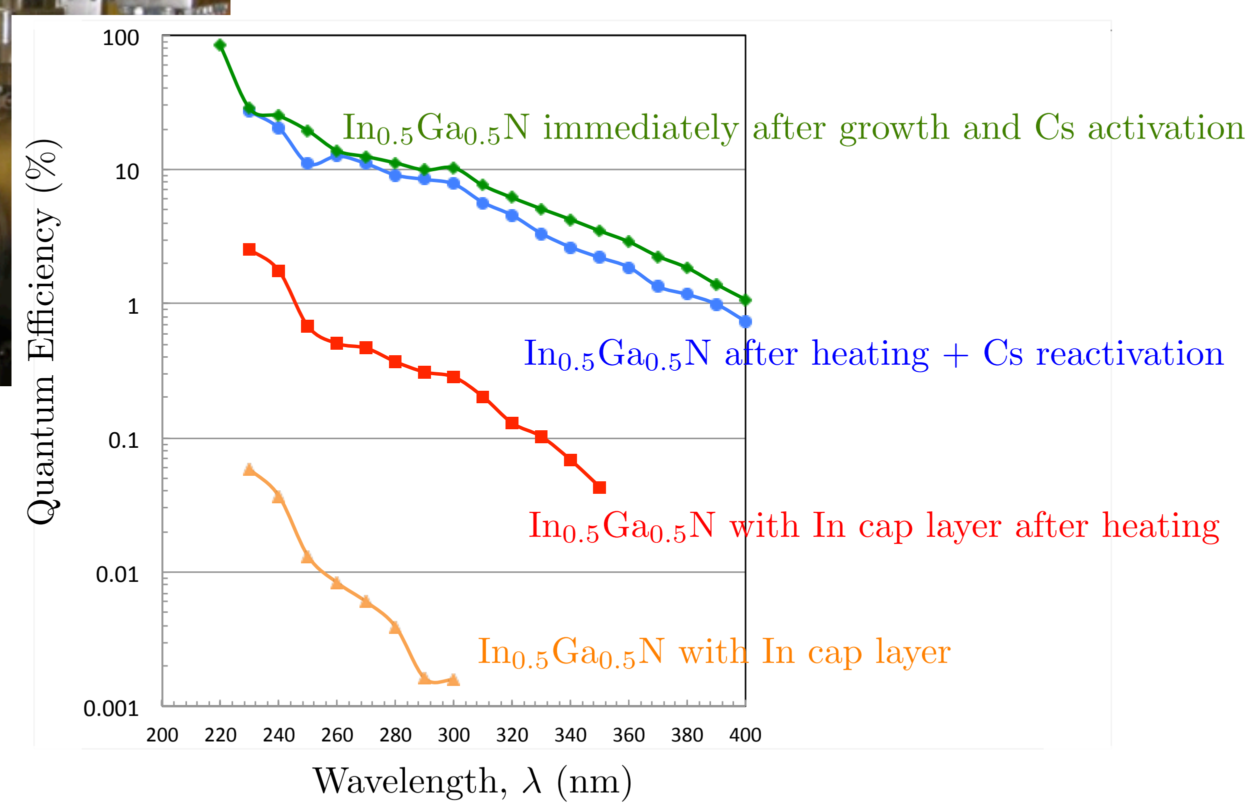
#3A photocathode uniformity

InGaN Photocathode Development – Washington University





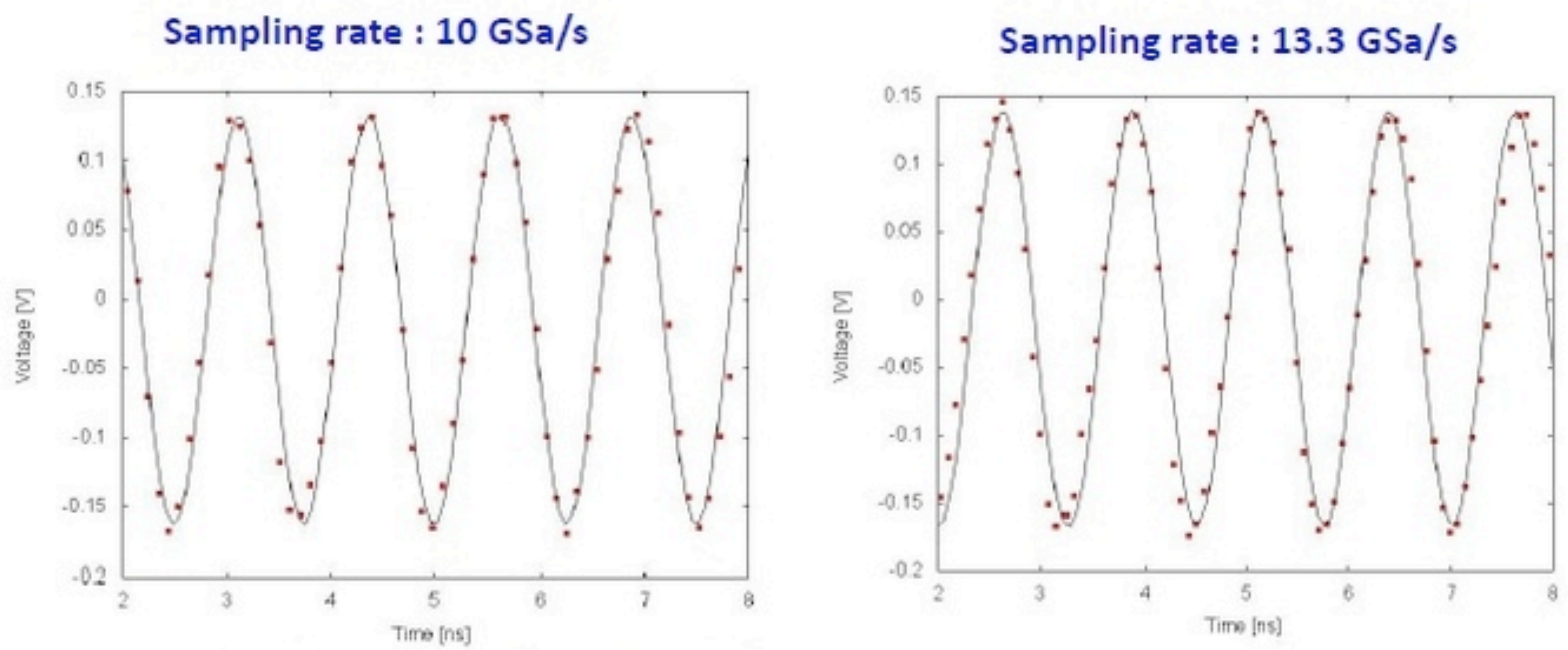




PSEC4 Performance

Digitized Waveforms

Input: 800MHz, 300 mV$_{pp}$ sine



- Only simple pedestal correction to data
- As the sampling rate-to-input frequency ratio decreases, the need for time-base calibration becomes more apparent (depending on necessary timing resolution)

Summary of Accomplishments 2009-2012

- ☑ Developed large area capillary arrays (20µm pore, L/D=60) for MCP substrate
  - Functionalized MCPs via separate Atomic Layer Deposition resistive and secondary emissive coatings
    - ☑ Demonstrated high gain (> 10^7) with little aging
    - Success recognized with R&D100 award 2012
- ☑ Characterization of SEE materials within Argonne MSD
- ☑ Established MCP test facilities at Argonne and SSL/UC-Berkeley
- ☑ Developed detector-to-computer DAQ based on PSEC4 ASIC with 1.6GHz BW, 10-15 GSa/s
  - Timing resolution: 6ps differential, 63ps single pe
- ☑ 8” photocathodes (SSL) with QE~25% @ 350nm with good uniformity & stability
  - Established photocathode lab at Argonne and made first 4”&7” photocathodes
- ☑ Demonstrated signals from o-ring sealed all-glass economical tile at Argonne
  - Process tank for 8” ceramic tube at SSL ready for commissioning
- ➡ Completing ceramic body braze at SSL and on-track for working sealed tube in Fall 2012
- ☑ Development of 4×3 tile SuperModule tray with complete readout chain

☑ Original Proposal Milestone
➡ Milestone yet to be achieved